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Impact of COVID-19 on the Environment, Economy, Society and Health in Southeast Asia

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Abstract

The COVID-19 pandemic has reversed many of the hard-fought gains made by Southeast Asian nations over the past few decades, not only damaging their healthcare systems but also impacting their economies, society, and environment. As an emerging region, Southeast Asia has suffered a heavy blow from COVID-19, with millions of people forced into poverty, enduring hunger, disease, and unemployment. Fully understanding the debilitating impact of COVID-19 is a critical prerequisite for Southeast Asian countries to "Build Back Better' in the post-pandemic era. To date, few studies have examined these comprehensive effects. To fill this lacuna, this study draws on the latest available data, applying the comparative research method to analyze the widespread impact of COVID-19 on the region. It not only offers some clarity as to what has happened in Southeast Asia but also provides a viewpoint of the short-and long-term effects and implications of COVID-19. In addition, this paper presents the critical interdependence of the environment, economy, society, and health and why recognizing this is crucial for Southeast Asian states to achieve effective recovery. Finally, based on an in-depth analysis, the paper argues that the optimal strategy that the region should employ to extricate itself from this tragic predicament is to adopt an integrated approach that takes into account environment, economy, society and health, when developing sustainable plans and practices for Southeast Asian states.

Keywords: COVID-19; Environmental impact of COVID-19; Social impact of COVID-19; Economic impact of COVID-19; Health impact of COVID-19; Confinement measures

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東南アジア諸国の環境、経済、社会、
および保健衛生におけるCOVID-19のパンデミックによる影響

シュー リキキ[*]・プテンカラム ジョンジョセフ[*]

要約

COVID-19のパンデミックにおいて、東南アジア諸国は過去数十年にわたって懸命に努力して得た利益の多くを損なった。

それは医療システムのみならず、経済、社会、環境にも影響を及ぼすものであった。

新興地域である東南アジアでは、何百万人もの人々がCOVID-19による大きな打撃を受け、貧困に追い込まれ、飢餓、病気、失業に苦しんでいる。COVID-19のパンデミックによる影響を完全に理解することは、パンデミック後の時代に東南アジア諸国が「より良い再建」を行うために必要であり、現在、これらの包括的な効果を検証することはまだあまり行われておらず、この研究は利用可能な最新のデータを利用し、比較研究方法を適用して、COVID-19が地域に及ぼす広範な影響を分析していくものである。

東南アジアで何が起こったのかを明確にするだけでなく、COVID-19による短期的および長期的な視点からその影響と意味について考察していきたい。

さらに、本論文では、環境、経済、社会、および保健衛生における相互依存性を検証し、東南アジア諸国が効果的な復興を達成するためにこの検証が役立つことを示したい。

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Impact of COVID-19 on the Environment, Economy, Society and Health in Southeast Asia

Introduction

The outbreak and rapid spread of Covid-19 have had disastrous consequences on the sustainable progress achieved worldwide in the past decade. As an emerging economy with a population of over 668 million[1], South-East Asia suffered a heavy blow from the first wave of the Covid-19 pandemic in January 2020. The region responded quickly and implemented effective public health measures to successfully curb the large-scale spread of the virus. However, since March 2021, the second wave, triggered by the new Alpha and Delta virus variants, has rapidly swept over the region. The exponential escalation of confirmed cases caused a collapse of the healthcare systems in the majority of SEA nations[2].

To combat the spread of the virus, the governments of SEA states have enhanced travel bans, movement restrictions, border shutdowns, and community quarantine[3]. Although these measures were effective in controlling the spread of COVID-19, they have had a significant adverse effect on economic growth. The travel industry and export trade have constituted the main driving forces of economic growth in most SEA nations over the past 20 years. Therefore, travel prohibitions and the disruption of supply chains due to the COVID-19 pandemic put many SEA countries in a difficult situation——an unprecedented economic crisis with millions of unemployed and company failures[4]. The surge in poverty, hunger, and inequality caused by the pandemic has reversed much of the region's sustainable progress achieved in past years. While the pandemic has reduced pollution in the industrial production and transportation sectors due to movement restrictions, it has also had a huge negative impact on the environment, economy, society, and health in SEA.

Praveena and Aris (2021) have argued that the COVID-19 lockdown and mobility restrictions have had a dual impact on SEA's environment: (a) the improvement of air and water quality, and reduction of urban noise and land surface temperatures, and (b) an increase in medical and plastic waste and damage to regional environmental sustainability[5]. Duncan Boughton et al. (2021) claimed that the COVID-19 pandemic has adversely affected agricultural production and food systems in SEA states[6]. Terence Tai Leung Chong et al. (2021) suggested that the COVID-19 pandemic has resulted in an economic slump and large-scale unemployment in the region[7]. Suriyankietkaew and Nimsai (2021) explained how the COVID-19 pandemic had affected SEA sustainable development and recovery strategies[8].

The above literature is important to understand some effects on the SEA region caused by the COVID-19, but they also show that there is a lack of comprehensive and in-depth studies about the impact of the pandemic on the whole region and the interdependence of the environment, economy, society, and health, based on sufficient and accurate data. To "build back better", it is crucial for SEA countries to better understand the substantial impact of COVID-19 on regional development, which is necessary to ensure that no one is left behind in the post-pandemic era. However, to date, research on this aspect remains scarce. To fill this lacuna, this study draws on the latest available data from verified sources, such as the OECD, IMF, the WHO, and the ILO, applying a comparative research method to analyze the widespread impact

of COVID-19 on the region. It not only offers some clarity as to what has happened in SEA region but also provides a comprehensive viewpoint of the short-and long-term effects and implications of COVID-19. In addition, the paper argues that the optimal strategy that the region should employ to extricate itself from this tragic predicament is to adopt an integrated approach that considers health, the environment, economy and society when developing sustainable plans and practices for SEA states.

Results and discussion

Below is a brief discussion and analysis of the impact of COVID-19 on the Environment, Economy, Society and Health in Southeast Asia.

Environmental impact

With the rapid spread of COVID-19 across the region, governments in SEA countries have implemented stringent domestic lockdowns for a relatively long period to protect people from infection[9]. Almost all mass gatherings, such as sports events, religious festivals, and cultural activities, have been canceled. A wide range of industries are prohibited from functioning normally because of these stringent restrictions. These lockdown measures have had a remarkable environmental impact. The most noticeable benefit was the dramatic improvement in air quality. Because of the closure of large-scale industrial production and less vehicular movement, waste emission, including CO_2 and other toxic suspended particles, has decreased at an unprecedented rate. The data from the World Air Quality Report published by IQAir indicates an amazing improvement in air quality in SEA, especially in Indonesia (Figures 1 and 2)[10]. However, although mobility restrictions led to a significant temporary improvement in air pollution in the region, waste emissions would substantially increase once the social lockdown is relaxed and economic recovery is initiated unless effective measures are adopted[11].

Figure.1 Global map of estimated PM2.5 exposure by country/region in 2019

Figure.2 Global map of estimated PM2.5 exposure by country/region in 2020

In addition, lockdowns and movement restrictions have had a dual impact on the biodiversity and ecosystems in SEA region. On one hand, the decrease in human movement has greatly alleviated ecosystem

pressure and benefited the recovery of biodiversity, particularly at some famous ecotourism sites. For example, during the national lockdown period, national park officials across Thailand documented increased wildlife sightings of dolphins, dugongs, reef sharks, and primates[12]; a similar situation also occurred in Indonesia. However, on the other hand, as economic depression has substantially reduced government income and plunged 104 million people into extreme poverty in SEA states[13], some important environmental conservation programs have been impeded due to lack of finance[14]; meanwhile, due to economic hardship, many people have turned to poaching, logging, illegal wildlife hunting and trafficking across the region[15], which puts decades' worth of progress in biodiversity and ecosystem conservation at risk of being lost in a short time. Satellite data from WWF Germany reveal that there has been an enormous rise in illicit logging and forest loss across Indonesia[16] In Cambodia, bushmeat poaching has increased since the Covid-19 pandemic outbreak. These activities not only cause ecological catastrophes but may also trigger another pandemic. As wildlife hunting, consumption, and trade bring animals into close contact with humans, this creates the conditions for the emergence of new intra-specific and inter-specific pathogen transmission, thus increasing the risk of developing new zoonotic infectious diseases[17].

Furthermore, other detrimental environmental consequences of the Covid-19 pandemic have occurred in SEA nations. The first is the surge in waste generation across the region, particularly contaminated medical and plastic waste. For example, the amount of medical waste in Bangkok, Thailand, has grown dramatically and sometimes surpasses one ton per day. Medical wastes such as PPE and gloves in Malaysia increased by 27% in March 2020 compared with 2019, followed by 31.5% and 24.6% increases in April and May 2020, respectively. The plastic waste crisis in this region has become more severe than in previous years. In Thailand, plastic waste grew to 6,300 tons per day in mid-May 2020 compared to 5,500 tons per day before the pandemic in mid-May 2019[18]. In Singapore, due to the mobility lockdown from April to June 2020, an additional 1,334 tonnes of plastic waste were generated from food delivery services and takeaways. The second negative consequence is the relaxation of environmental regulations. Some governments have delayed or weakened their environmental management policies and regulations after the outbreak. For example, Quezon City, located in the Philippines' most populous highly urbanized area, postponed its implementation of a ban on single-use plastics, originally planned for July 2020, to March 2021[19].

In summary, the COVID-19 pandemic has had some positive consequences within a short time, including improvement in air quality, reduction in pollution emissions, and mitigation of ecological pressures. In comparison, the pandemic has also generated many significantly negative environmental effects, such as the rapid increase in medical and plastic wastes, delays in the implementation of important environmental programs, increase in illegal logging and wildlife hunting, and the relaxation of environmental regulations. Another critical impact of the COVID-19pandemic is the escalation of future uncertainty in regional ecological environments. On the one hand, the pandemic has given rise to opportunities for SEA countries to decrease fossil energy consumption, alleviate climate warming, and re-examine the relationship between humans and nature by changing the traditional ways of human production and consumption and by promoting green development in post-pandemic recovery plans. However, it may also intensify environmental risks in the region, especially in low- and middle-income countries. Economic

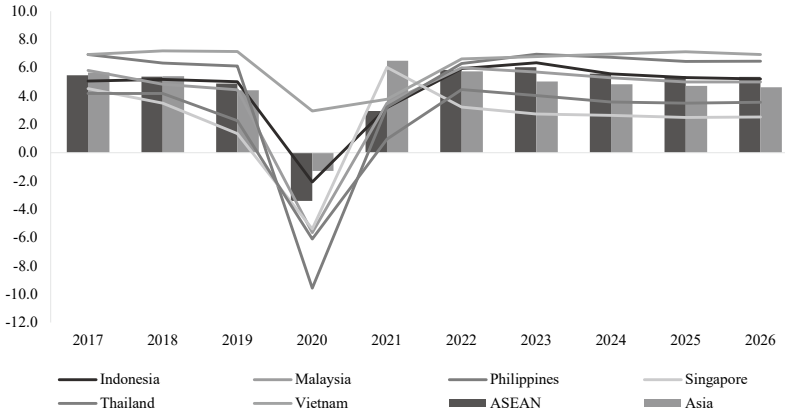
recession has meant that more people have fallen into poverty and increased government debt; survival pressures tend to force people and governments to go back to the "old" ways——sacrificing environment for economic growth. Considering that all SEA countries have lagged in all but two of the 17 SDG goals since 2000[20], the choices they make in terms of recovery strategies would play a crucial role in the future sustainability of the environment in the region.

Economic Impact

Most SEA countries have experienced miraculous growth thanks to export-oriented growth strategies in the past two decades[21], but the COVID-19 pandemic has brought their economies to a standstill. To control the spread of the virus, governments in SEA countries have taken wide-ranging confinement measures, such as lockdowns, travel restrictions, business closures, and community quarantines, which have resulted in a sharp decline in tourism, the disruption of supply chains, reduced export demand, and a disastrous impact on the regional economy[22]. To deal with the economic slowdown, governments in SEA countries have implemented various fiscal policy packages and triggered a rapid increase in national fiscal deficits.

The most apparent economic fallout from the pandemic is characterized by the deeper-than-expected contraction of GDP in SEA region. Tourism and export-oriented industrialization had helped sustain the rapid economic growth of most SEA countries in recent years. The dramatic decline in the number of tourists due to travel restrictions has pushed thousands of restaurants, hotels, and related small businesses to the brink of collapse. According to the data from ASEAN Statistics Division 2021, the number of visitor arrivals in SEA grew sharply from 37 million in 2005 to nearly 144 million in 2019, but there has been a rapid decrease in 2020, ranging from approximately 50% to 80%, close to 100% in some famous destinations like Bali[23] Apart from the huge loss to the tourism industry, SEA's export volumes encountered a rapid drop in 2020 (except Vietnam). Export-driven growth in the region depends on the demand for export destinations and supply of intermediate inputs, mainly from China, Japan, and the Republic of Korea[24]. Due to the disruption of supply chains, the demand for export destinations sharply decreased in 2020, which dealt a heavy blow to the export industry in SEA region. The downturn in the tourism and export industries led to GDP growth in SEA countries that was lower than the 2020 and 2021 Asian average. The dramatic drop in GDP growth presented in Figure 3 shows that the COVID-19 pandemic has hit the main ASEAN countries very hard, especially Thailand and the Philippines.

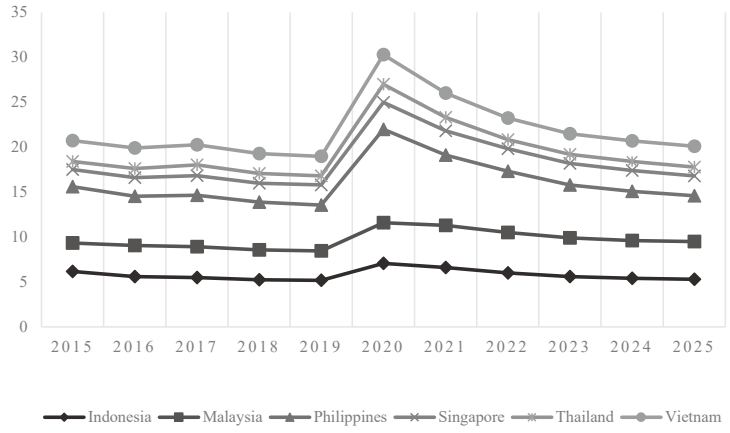
Figure.3 GDP Growth Rate of 6 ASEAN Countries (%)



Source: Based on data from Asia and Pacific Regional Economic Outlook (2021) and IMF, authors have redesigned the Figure 3.

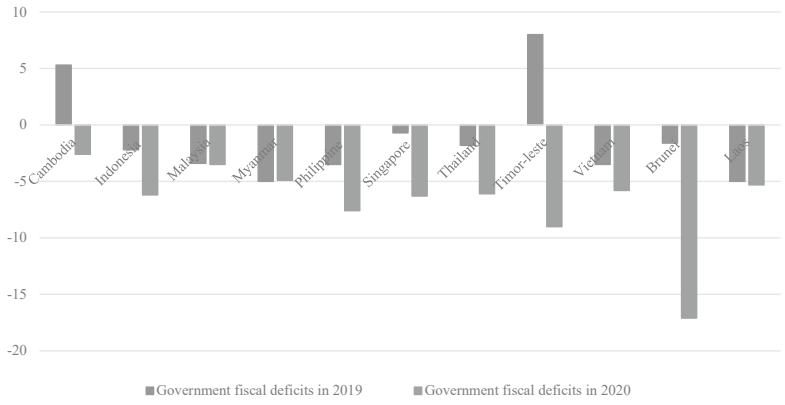
As a result of the economic downturn, SEA region was confronted with an abrupt increase in unemployment in 2020 and 2021, in contrast to the previous year (Figure 4). Due to the weak labor systems in most SEA states, there were numerous informal workers before the pandemic, accounting for 76% of the regional total employment[25]. The majority of these workers worked in the sectors worst affected by the pandemic, such as food services, accommodation, wholesale, and retail trade[26]. A 2019 ASEAN report estimated that 57.5 million informal workers worked in these four sectors in eight of the 10 ASEAN member states (excluding the Philippines and Singapore, which have no data) before the COVID-19 outbreak. In Vietnam, Myanmar, Laos, and Cambodia, the informal employment rate in the food services and accommodation sector accounted for 81–89%, and in wholesale and retail trade this figure was 70–97%. After the pandemic began, these people were the hardest hit, as they did not have automatic access to social security when they lost their jobs[27].

Figure.4 Unemployment Rate of 6 ASEAN Countries (%)



Source: Based on data from Asia and Pacific Regional Economic Outlook (2021) and IMF, authors have resigned the Figure 4.

Figure.5 Government Fiscal Deficits between 2019 and 2020 in Southeast Asia



Source: Data from Asian Development Bank.

To prevent economic slowdown and reduce job losses, governments in SEA countries have provided a range of fiscal support, including direct cash disbursement, forgivable loans, and deferment of payments[28]. All governments in the region have increased their fiscal expenditures, while government revenues dramatically decreased due to lower tax revenue triggered by the economic depression. Increased spending and decreased income result in a larger fiscal deficit[29] which means that a greater portion of government income must be used to repay debts in the coming years, and the money to spend on other sectors, such as innovation, public health, and infrastructure, will essentially be reduced. For most SEA countries that remain in the low-middle-income bracket, large debt repayments may jeopardize their future.

In summary, the fight against the COVID-19 pandemic has caused huge economic losses in SEA region. Employment growth, poverty alleviation, and human development programs have all been dramatically rolled back. More importantly, regional economic recovery remains uncertain. On the one hand, because the spread of the virus in individual countries has still not been controlled, various containment measures could not be completely canceled in a short time. On the other hand, because of the export-oriented economic strategies of the majority of the SEA states, the speed and depth of regional recovery will depend, to a great extent, on the global market reviving. Moreover, the COVID-19 pandemic has had a varying impact on SEA economies. Some suffered tolerable economic blows, while others were hit harder. For those countries where many people are struggling to escape poverty or change their status from poor to low-income, the recovery path will be longer and harder.

Social Impact

Although SEA region adopted COVID-19 containment measures relatively early and seemed more effective in doing so than other regions in the world in 2020, the overall damage caused to regional social development remains immeasurable[30]. This has become especially apparent since the widescale spread of the Delta variant, which has caused a massive increase in poverty, food insecurity, inequality, and education deficit, making the achievement of SDGs even more urgent[31].

Poverty and food insecurity

The rise of the "new COVID poor" has exacerbated existing food security risks across the region, rolling back much of the positive progress made by the majority of SEA nations in addressing poverty and food insecurity over the past two decades[32]. As the economic depression triggered large-scale unemployment, the number of families in desperate need of governmental financial support and assistance grew rapidly. Most countries in the region must overcome these rising poverty problems. According to World Bank (2021) calculations, the total number of poor people in East Asia and the Pacific is estimated to be 19 million (at $3.20 PPP/day) and 29 million higher (at $5.50 PPP/day), respectively, in 2021, compared to the pre-COVID-19 crisis period[33]. In Thailand, about 1.5 million Thais fell into poverty as a result of the COVID-19 pandemic, with the total number of poor people growing from 3.7 million in 2019 to 5.2 million in 2020[34] In Indonesia, about 2.76 million people slipped below the poverty line from September 2019 to September 2020; thus, the number of people living below the poverty line reached 27.55 million in 2020 and accounted for 10.2% of the total population[35]. Other low-income countries in the region, such as Laos, Myanmar, and Cambodia, also faced similar pressures due to economic stagnation, unemployed growth, and income losses, resulting in increased poverty to varying degrees[36].

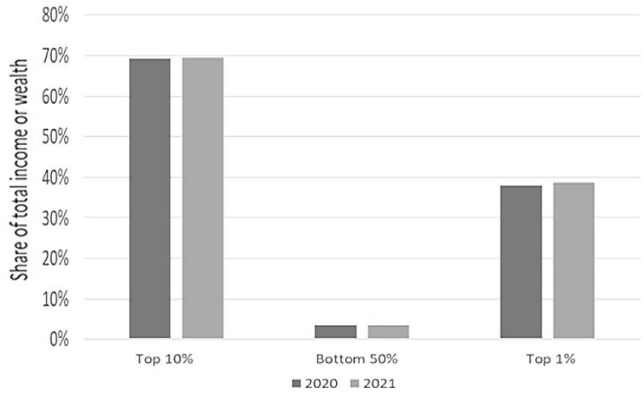
Income decline and poverty have further aggravated food insecurity in SEA nations. The number of undernourished people and people suffering moderate or severe food security in the region increased by 2.8 million and 14.5 million, respectively, from 2019 to 2020[37], reflecting the precarious situation of food and access to food. Farming remains a major source of income in most SEA countries. However, movement restrictions caused acute labor shortages and triggered decreases in agricultural productivity and rural income. Moreover, strict lockdown measures disrupted food supply chains, increased the costs of farming production and transportation, and led to a rise in food prices. For people living in low- and middle-income countries, who need to spend a larger part of their income, than those in rich countries, to sustain their families, economic difficulties prevent them from purchasing sufficient food[38]. If governments in the region cannot take swift measures to solve food insecurity, more vulnerable groups, including farming populations, will face the immense threat of hunger and malnutrition.

Inequality

The COVID-19 pandemic has greatly aggravated pre-existing inequalities within the region in multiple ways, including by aggravating income and wealth disparities, and increasing educational gaps and gender inequalities. With the spread of the COVID-19 pandemic, wealth disparities between the poor and rich have increased rapidly in SEA states. In 2020, the richest 10% of the region owned nearly 69.1% of its total wealth. By 2021, this ratio had increased to 69.6%. Compared with the wealth growth of the rich, the wealth of the bottom 50% decreased from 3.42% to 3.4% during the same period (Figure 6). Moreover, this gap continues to widen with the prolonged COVID-19 crisis[39]. In the main ASEAN states, not only has the number of billionaires increased rapidly since the COVID-19 pandemic began, but also the rate of wealth accumulation has been shocking (Table 1). Before the COVID-19 outbreak, SEA region was falling short of meeting the SDGs, because rapid economic growth has been associated with high-level inequality in the long term[40]. The COVID-19

pandemic has resulted in a significant spike in economic inequality across the region. Given the growing societal tensions triggered by the wealth gap, governments in SEA states should pay more attention to this issue.

Figure.6 Wealth Inequality between 2020 and 2021 in Southeast Asia



Source: Data from World Inequality Database

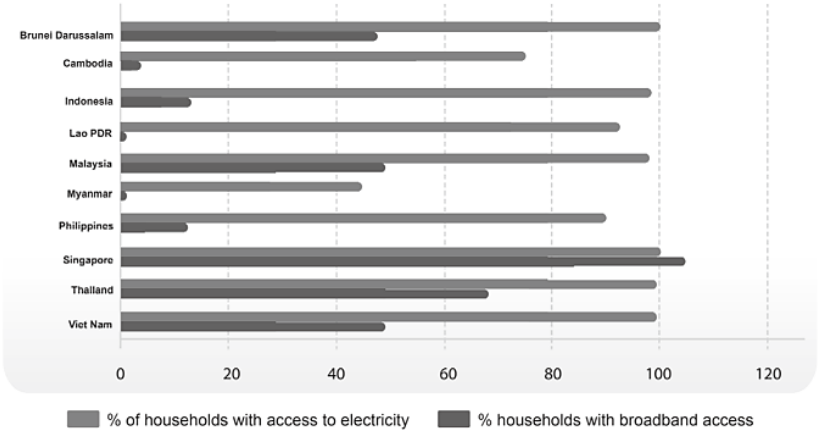
Table.1 The Growing Wealth of South-East Asia's Millionaires during the COVID-19 Pandemic

Country	March 2020		Nov 2021	
	Wealth, $bn	Number of billionaires	Wealth, $bn	Number of billionaires
Indonesia	53.7	15	91	21
Malaysia	44.7	12	59	16
Philippines	31	15	45	16
Singapore	90.7	27	137	29
Thailand	66.4	20	78	29
Vietnam	10.2	4	20	6

Source: https://www.forbes.com/billionaires/

Apart from economic inequality, the pandemic has exacerbated the existing educational gaps in SEA region and caused greater inequalities that may undermine future human capital and welfare owing to learning loss and an increase in dropout. After July 2020, schools and universities closed across the region because of the COVID-19 crisis. More than 152 million children and youths are affected. The closure of schools has posed an immediate and uneven impact on the population in the region due to unequal access to infrastructure, devices, and resources, a basic premise for quality multimodal teaching and learning[41]. Figure 7 shows the enormous disparities in households with electricity and broadband in all ASEAN countries. While these countries moved to remote learning modalities during the pandemic, children from poor families and economically backward areas who could not afford electronic devices and internet connections due to lack of money had considerably fewer opportunities to engage in online or face-to-face learning activities than those from wealthy families and economically developed areas. Another crucial factor in intensifying learning loss is the shortage of essential support for poor families and weak students during school closures.

Figure.7 Electricity and Broadband Internet Coverage across the Region



Sources: World Bank 2020; International Telecommunication Union 2019b. Authority for Info-communications Technology Industry of Brunei Darussalam 2016; Ministry of Finance And Economy, Brunei Darussalam 2016; Minges 2018; Electricity Authority of Cambodia 2020; Sulaiman 2019; Yap 2017; Unit 2015; EuroMonitor n.d.; Eleven Media 2019; Asian Development Bank 2018; Singapore Open Data 2019; Singapore Department of Statistics 2019b; Infocomm Media Development Authority, Singapore 2019; Provincial Electricity Authority n.d.; General Statistics Office of Vietnam 2018; General Statistics Office of Vietnam 2019.

In addition, gender inequality has similarly increased across the entire region. Since the COVID-19 outbreak, domestic violence against women and girls has escalated in SEA states. Women across the region suffered more violence than men due to food insecurity caused by COVID-19 and the lack of economic empowerment; 25% of respondents in Lao PDR and 83% in Indonesia thought that domestic violence intensified because of the pandemic. In Thailand, the number of domestic violence cases doubled during the quarantine period[42]. Similar increases have occurred in Singapore and Malaysia[43]. Based on a recent study conducted in Vietnam, 99% of 303 women aged 18–60 years suffered either economic, psychological, physical, or sexual abuse during the lockdown; 84% said that they experienced more violence than before the pandemic, while 80.7% reported that they were physically injured during these fits of rage[44].

In short, the COVID-19 pandemic has had a significant negative social impact on SEA region. The increasing poverty, food shortage, and unequal access to income, education, and other infrastructure reduce the life opportunities of those who already face numerous inequalities. If the problem of huge socioeconomic inequality is not addressed swiftly by social reform, SEA region will face an uncertain future. New inequalities will soon emerge, and more children and youth will be trapped in a vicious cycle and fall further behind[45]. When that occurs, SEA region as a whole will be thrown into continual political and economic unrest.

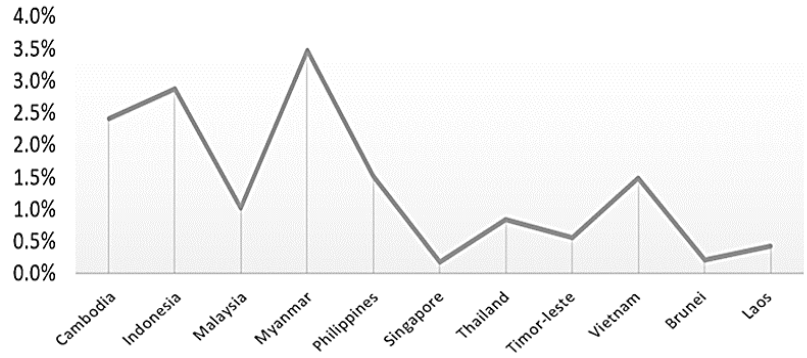
Health Impact

SEA region was regarded as a successful model because of the public health measures effectively implemented during the first wave of COVID-19 in 2020. However, the rapid spread of Alpha and Delta variants in the region from March 2021 transformed the situation[46]. The exponential growth in the infection rate, compounded by the shortage of healthcare instruments, triggered a collapse of the healthcare system

and a substantial number of deaths and years of life lost in most Southeast Asian countries[47]. Based on the data published by the WHO Dashboard (until February 21, 2022), the total number of confirmed cases and deaths in SEA region surpassed 18 million and 310,000, respectively.

The health impacts resulting from COVID-19 vary greatly due to the huge gaps in socioeconomic development and public health coverage within the region's countries; the low- and middle-income countries suffered the most severe shock. In Figures 8, we see that the death rates in Indonesia, Myanmar, and Cambodia are 2.9%, 3.5%, and 2.4%, respectively, far higher than those in Singapore (0.2%), Thailand (0.8%), and Malaysia (1.0%). Given the significant disparity in health information systems and the limited testing capacity in developing countries, published data on deaths and confirmed cases in SEA region are probably considerably lower than the real number[48]. Moreover, increasing evidence has shown that COVID-19 can result in long-term and lingering symptoms called post-COVID-19 syndrome in some patients recovering from the infection, such as fatigue, headache, concentration disorder, and lung damage[49]. It is therefore impossible to assess all direct health impacts on infected people in the short term; other far-reaching effects on public health will require additional time to identify and verify over a sufficient time span.

Figure.8 Fatality Rate of COVID-19 in Southeast Countries (to February 21, 2022)



Source: Calculated based on the data from World Health Organization.

In addition to direct health impacts, there were huge and indirect negative effects on prevention and treatment services for non-communicable diseases due to disruption caused by the pandemic to the supply and demand for health facilities and care personnel[50]. Confronted with the rapid spread of COVID-19 across the region, most SEA countries had to reallocate scarce medical resources and national funds in order to reduce morbidity and mortality from the pandemic, which resulted in the denial of urgent health services and medicines to many people with other diseases such as cancer, chronic dermatitis, cardiovascular disease, pneumonia, and diabetes, particularly in low-income countries[51].

Even routine immunizations in children have been significantly affected, for example, approximately 84% of immunization services in Indonesia ceased operations, especially for the MMR vaccine[52]. In Singapore, there was a 25.6–73.6% decrease in MMR uptake rate and 8.0–67.8% drop for PCV[53]. In addition, public health sector funding for other disease control programs such as HIV, malaria, and TB have been cut

down to support COVID-19 containment. For example, it is well known that SEA region remains a high-risk tropical area for malarial outbreaks and plays a pivotal role in global malaria elimination and eradication strategies. However, almost all malaria activities planned for 2020 have been disrupted because of the reprioritization of the national budget and lockdown policies in some SEA countries, including Indonesia, which has the highest burden of malaria in the region[54]. These complications resulting from the COVID-19 pandemic have led to an enormous number of deaths and potential years of life lost.

In summary, the COVID-19 pandemic has caused an immense loss of life across SEA region. This poses a severe threat to regional sustainability. In most SEA countries, investment in health has remained lower than economic growth for a long time. Out-of-pocket spending is far higher than the global average. These inadequacies have greatly augmented the mortality rate due to COVID-19 and other non-communicable diseases in the region, particularly in low- and middle-income countries. To mitigate health losses in future crises, it is crucial for SEA states to re-examine the role of sound healthcare systems in national development, increase governmental health spending, and establish adaptable health systems.

Conclusion

Not only has the COVID-19 pandemic shown how an infectious disease can set back socioeconomic achievements by years in the SEA region, but also how vulnerabilities in healthcare systems can have a huge impact on public health and environmental conservation. The COVID-19 crisis has revealed that SEA states have paid a huge cost by neglecting the interdependence of economic, social, environmental, and health factors in traditional development models for a long time. This provides a window of opportunity for all SEA states to rethink development and promote a model shift towards sustainable development in the post-pandemic era. The COVID-19 pandemic is not likely to be the last; the question is how SEA region will prepare for the next pandemic? Every country and government must draw upon the lessons from the current crisis to make changes necessary to defeat the next outbreak.

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渡良瀬遊水池の水環境を評価する指標としての藻類の使用

董祺・黄光偉

要旨

藻類は水質環境の変化に敏感であるため、群落種類構成、優占種、現存量などの指標が栄養レベルの異なる水環境で変わり、そのため水域の生態環境状況を迅速かつ正確に総合的、反映することが解る。本研究は、渡良瀬遊水地の植物プランクトン群落構造、多様性を検討することであり、生物学的指標と理化学的指標を組み合わせ、渡良瀬遊水地の水質状況を総合的に分析し水体栄養等級を検討した。また植物プランクトンの密度、種類および多様性と季節変化との相関性を分析し、渡良瀬遊水地の管理と環境保全に科学的根拠を提供すると同時に、水生態健康指標および水生態修復評価に理論的根拠を提供することを目的とした。プランクトン群集の種の多様性および豊富性データ（Margalef豊富性指数、Shannon-Wiener多様性指数、Simpson指数など）と比較される。生物指標、理化学水質指標、プランクトン群集と水質指標との関係を用いて決定され、プランクトンを指標として水質と生態環境を評価することを紹介した。

キーワード：渡良瀬遊水池、藻類、水環境、評価

Evaluation of water environment in Lake Yanaka using phytoplankton as indicators

Qi Dong, Guangwei Huang

Abstract

The species composition, dominant species, extant quantity, and other indicators of algal communities sensitive to environmental changes in water quality vary in water environments with different nutrient levels. Thus, algae can reflect the ecological conditions of waters in a timely, accurate, and comprehensive manner. The main objective of this study is to investigate the community structure and diversity of phytoplankton in the Watarase Retarding Basin, to analyze the water quality of the Watarase Retarding Basin in combination with biological indicators, physical and chemical indicators, and to analyze the correlation between phytoplankton density, species, diversity, and seasonal changes, to provide a scientific basis for the management and environmental protection of the Watarase Retarding Basin. It also provides a theoretical basis for the evaluation of water ecological health indicators as well as water ecological remediation. In this study, the species diversity and richness data (Margalef richness index, Shannon-Wiener diversity index, Simpson index) of the phytoplankton community were compared, and the relationship between biological indicators, physical and chemical indicators, plankton community, and water quality indicators were analyzed, and the plankton was used as an indicator for evaluating water quality and ecological environment.

Keywords: Watarase Retarding Basin, phytoplankton, water, evaluation

渡良瀬遊水池の水環境を評価する指標としての藻類の使用

1．はじめに

プランクトン群集は水質の影響を反映することができる[1]。藻類は生物学的モニタリング指標として水環境評価に広く利用されていて、藻類を水質生物モニタリングの指標として利用するのはすでに100年近くの歴史があり、現在大量の文献は藻類を利用して水体の栄養状況を評価することを報告している。海外では藻類の水質モニタリングへの応用が比較的に早く、1909年にドイツの学者KolkwitzとMarssonは藻類を利用して汚染水質を評価する方法を提出し、水体の汚染程度の違いについて分類を行った。1950年代以降、多くの学者が簡単な生物指標と種多様性指標を用いて水質状況を監視し良好な結果を得た。

日本国土交通省国土保全局の資料などによると、日本の生活用水と工業用水は1960年代半ばから2000年にかけて約3倍に増加した[2]。21世紀に入ってからは、経済成長率の鈍化や人口の頭打ちなどに伴って生活用水使用量は毎年ほぼ横ばいで推移し、またリサイクルの推進などに伴って工業用水使用量も毎年横ばいから減少の兆しを見せている。

水質問題は人間の健康や生活環境、水生生物に大きな影響を与えるからである。国連環境計画（UNEP）の調査によると、全世界の30～40%の湖では、貯水池の富栄養化の影響度が異なることが示されている。スペインの800の貯水池のうち少なくとも1/3の湖が重度栄養化状態にあり、南米、南アフリカ、メキシコおよびその他の場所で水体重栄養化が報告されている。日本では1984年に「湖沼水質保全特別措置法（湖沼法）」が公布され、湖沼法が施行されて数年が経つが、湖沼の水質改善は期待されていない[3]。

国際経済協力開発機構（OECD）による湖沼の富栄養化とは、栄養塩の増加による水域中の藻類の急速な繁殖により、水域の溶存酸素の低下、水質の悪化、魚類その他の水生生物の死亡を引き起こす現象である。湖の水体が富栄養化状態を呈するとき、主に浮遊藻類が大量に繁殖成長することを表現している。

植物プランクトンの季節変化の生長規則について、国内外の多くの学者が研究を展開した。その中で、最も影響力があるのはSommeの温帯湖プランクトンと理化学因子データの分析を通じて、有名なPEG（Plankton Ecology Group）モデルを提出した。プランクトン群落の季節の遷移は一般的に冬と春の珪藻とクリプト藻から夏の緑藻に変化し、夏の終わりと秋の初めには藍藻が優勢になると考えている。 秋の到来とともに珪藻の重要性が再び上昇し、主な影響因子は水温である[4]。

2．渡良瀬遊水地

渡良瀬遊水地（北緯36度13分5.54秒、東経139度40分30.64秒）は、足尾鉱毒事件による鉱毒を沈殿させ無害化することを目的に、渡良瀬川下流に作られた日本最大の遊水池である[5]。1887年時に、上流の足尾銅山の汚染が流出し、約380世帯2500人の谷中村が廃村となり、1973年度に、

足尾銅山は閉鎖され、人々の努力によりこの地域の汚染状況は著しく改善された[6]。谷中湖は洪水防止と都市給水を主な用途とする多目的貯水池であり、フォルミディウム藻（Phormidium）の大規模な蔓延を防止するために1997年から湖床排水対策が実施されている。現在、この遊水地中、約1,500ヘクタールのヨシ原があり、植物で約1,000種、鳥類約260種、昆虫類約1,700種、魚類約50種の生態系が形成されている。そのうち、国指定の絶滅危惧植物が60種類、野鳥は44種、昆虫では23種の国指定絶滅危惧種が生息している[7]。2012年7月3日付でユネスコのラムサール条約湿地登録地に認証され、湿地システムの生物多様性保護区として国際社会から注目されている。水道水としては、一都四県（東京都、栃木県、茨城県、埼玉県と千葉県）に供給されている。

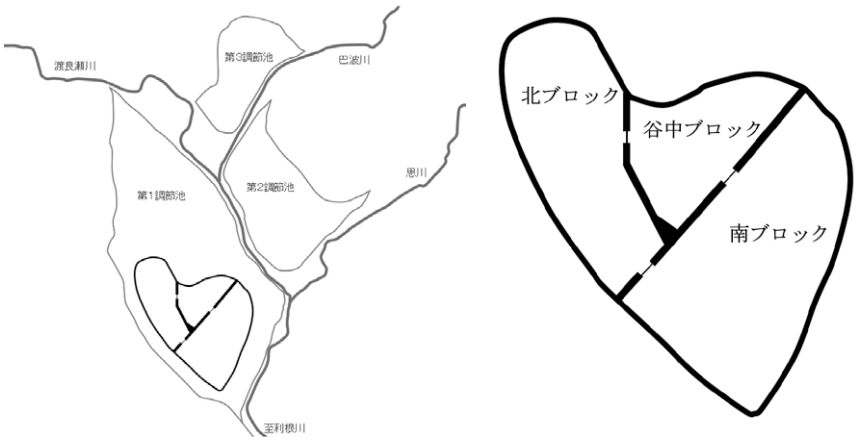

図2.1　渡良瀬遊水地

2.1 研究方法

渡良瀬遊水地における浮遊藻類種の観察と群落組成の調査のためには、サンプリング地点における水試料の取得と前処理、浮遊藻類群落の観察と画像化、浮遊藻類種の識別と計数の一連の操作が必要である。

採水器で表層（水面から0.5m）に1Lのサンプルを採取し、15mlのルゴール溶液を注入し、浮遊藻類の定性と定量分析に用いた。現場で溶存酸素（DO）、pH値、水温(T)、NO3-、電気伝導率（COND）などの指標を現場で測定し記録する。また表層水サンプルを採取して実験室でアンモニウム（NH4+）、亜硝酸塩（NO2-）リン酸塩（PO43-）CODなどの理化学値の測定に用いた。

2.2 研究地域

調査期間は2019年11月から2020年11月までの1年間とした。2019年11月、（緊急事態発表のため春のサンプリングは行わなかった）2020年6月、8月、9月と11月の5回の水質調査を行った。毎回、谷中湖の数か所において、表層水面下0.5mの度水サンプリングを採取して藻類調査を行った。

3. データ分析

水試料を採取した後、前処理、顕微鏡観察、画像取得、種同定、プランクトン数カウントを調べ、約700のプランクトン群集の画像と大量のプランクトンデータが得られた。

表3.1 植物プランクトンの平均密度

時間	2019年11月	2020年6月	2020年8月	2020年9月	2020年11月
平均密度（inds/mL）	802	1172	18100	11262	29765

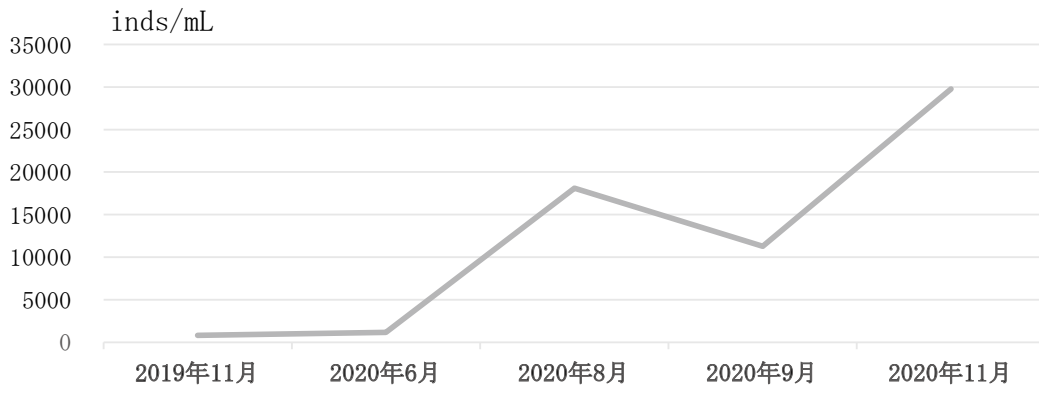

図3.1　藻類密度の折れ線グラフ

3.1 渡良瀬遊水地浮遊藻類密度

渡良瀬遊水地浮遊藻類密度の推移を図3.1に示すと、渡良瀬遊水地浮遊藻類密度の変化は8月にピークを示している。6月から水温が徐々に上昇し、水体中の浮遊藻類は蘇り始まり、特に藍藻、緑藻である。数量は急激に増加し、8月はピーク時期に到達した。9月に比べて11月に藍藻類の数が増加したのは、秋の栄養塩濃度が高く、特に窒素濃度は高いため、藍藻類は窒素固定作用があり、十分な窒素塩が藍藻類の成長に栄養を提供した。調査期間浮遊藻類4綱45属88種（変種を含む、）が検出された。藻類の個体群構成は緑藻の割合率が最も大きく（47.6%）、19属41種が検出され、珪藻が19属35種、藍藻類が6属7種であり、クリプト藻種は1種と検出された。

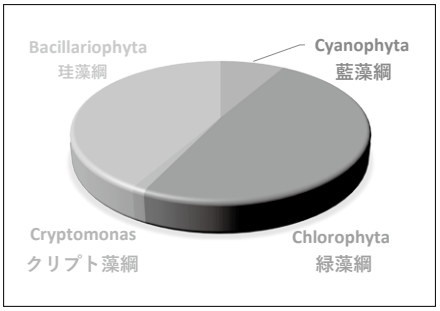

図3.2　4種類藻類の割合

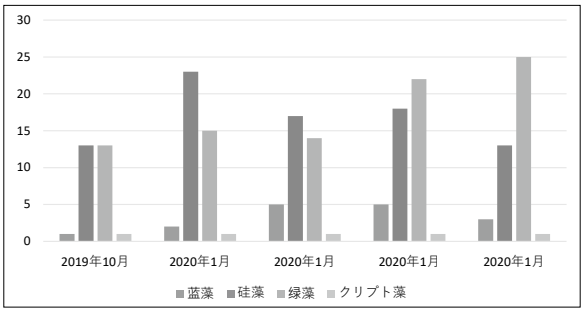

図3.3　藻類種数の柱状グラフ

多様性生物指数は浮遊藻類の細胞密度と個体群構造の変化から水体の汚染度を評価する。生物多様性指数の理論基礎は、浄化された水体の中にあり、生物の種類が多様で、数量が少ないことである。汚染された水の中で敏感な種類は消失し、汚染に強い種類は大量に繁殖し、種類は単一で、数量は比較的に大きい[8]。藻類多様性指数が高いほど、群落構造の安定性が大きく、水質が良いことを示している。生物多様性の評価指標としては（Shannon-Wiener）多様性指数、（Margalef）豊富度指数、（Pielou）均一度指数、（Simpson）優位度指数などがよく用いられている。

表3.2　富栄養化評価の生物学指標

富栄養化評価のための生物学的指標							
評価指標	評価基準						
	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ
密度（$\times 10^3$/ml）	≥100	100～80	40～80	10～40	1～10	0.5～1	≤0.5
優占種	Cyanophyta, Chlorophyta, Bacillariophyta, Euglena		Cyanophyta, Chlorophyta, Bacillariophyta, Cosmarium			Dinoflagellate, Chrysophyceae, Bacillariophyta	
豊かさ指数（d）	0～1	1～2	2～4		4～6	>6	
多様度指数（H）	0～1		1～3			>3	
均等指数（J）	0～0.3		0.3～0.5			>0.5	

Ⅰ：超富栄養；　Ⅱ：富栄養；　Ⅲ：中―富栄養；　Ⅳ：中栄養；　Ⅴ：貧―中栄養；　Ⅵ：貧栄養；　Ⅶ：きれい

表3.3　渡良瀬植物プランクトン生物指数表

時間	2019年11月	2020年6月	2020年8月	2020年9月	2020年11月
Simpson (d)	3.34	4.35	3.16	3.94	3.56
Pielou (J)	0.41	0.46	0.046	0.277	0.32
Shannon-Wiener (H)	1.37	1.73	0.17	1.06	1.21
Margalef (D)	0.27	0.812	0.056	0.483	0.64

6月の優位度指数（Simpson）が4～6範囲で、水質はほかの時期に比べてより健康であり、生物の多様性が高いことを示している。

3.2　水質環境現状の分析

浮遊藻類は水体生態系の重要な構成要素であり、成長状況と群落分布の特徴の変化は水温、溶存酸素、窒素、リン素、栄養塩など多くの理化学的指標の影響を受け、また水文、水動力学条件の変化も藻類の成長と繁殖に影響を与える。

表3.4　温度、pH、DO、NO_3^-、COND、PO_4^{3-}のデータ

時間	2019年11月	2020年6月	2020年8月	2020年9月	2020年11月
温度	12.9	20.5	34.8	39.0	13.7
pH	8.15	7.87	9.13	8.83	8.60
DO (mg/L)	12.59	8.69	12.01	11.06	14.14
NO_3 (mg/L)	8.5	12.0	17.0	13.0	8.0
COND (us/cm)	91.5	159.7	167.3	165.3	160.0
PO_4^{3-} (mg/L)	>0.1	>0.1	>0.1	0.1	>0.1

調査期間中、渡良瀬遊水地水体のpH値は7.8～9.2の範囲で弱アルカリ性であった。全体として、渡良瀬遊水地の水体pH値は比較的安定しており、その変動幅はそれほど大きくないことから、渡良瀬遊水地pHは浮遊藻類の生育の主な影響因子ではないと判断された。

表3.4の溶存酸素データから、11月には湖水温度が低く、湖水の溶存酸素含量が高くのこと分かった。6月には水温が上昇し、水中の微生物による有機汚染物の分解、底泥の分解による酸素消費、水生生物の呼吸による酸素消費が増加し、水体の溶存酸素含量が低下した。それに伴い、水中の浮遊藻類が大量に繁殖し、光合成作用が強くなり、大量の酸素が放出され、水体の溶存酸素含量が多くなる。全体的な溶存酸素量の変化傾向は春季が低く冬季が高く、水体の自浄能力が比較的強い。窒素含有量が11月に最低濃度で、藍藻類の密度変化とほぼ一致した。

表3.5　重金属イオン

イオン	No.1	No.2	No.3
Pb (mg/L)	0.14	0.16	0.15
Cd (mg/L)	<0.01	<0.01	<0.01
Cu (mg/L)	<0.10	<0.10	<0.10

表3.5で測定した重金属イオン濃度と合わせると、渡良瀬遊水地の重金属イオン含有量は現在すべて安全範囲であり、鉱毒事件後の処理が重金属汚染の解決に有効であることが示される。

3.3 渡良瀬遊水地の指標プランクトン

いくつかのプランクトンはある種の汚染物質に敏感で、汚染物質が水の中に現れたとき、その数量が減少したり消えたりする可能性がある。変化の背景においても、指示種は水生系の「健康」状態を反映して、初期警報信号として利用できる[9]。

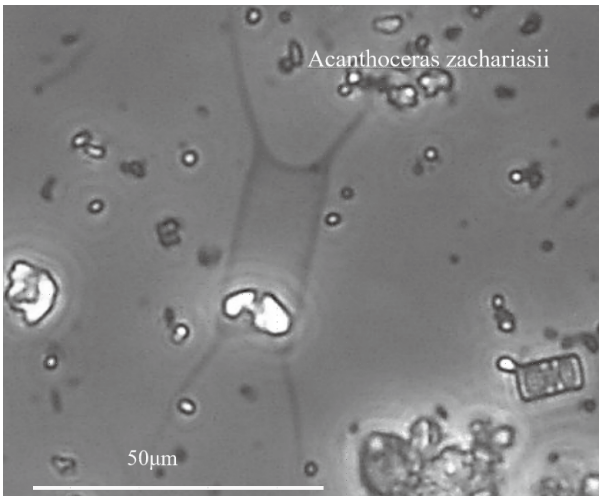

図 3.4 Acanthoceras zachariasii

珪藻綱の Acanthoceras zachariasii 的存在、よく使われてきたシノニムは Atteya zachariasii。このプランクトンは各地の湖沼に広く分布する普通種、貧栄養性。多産すると、水道のろ過障害の原因生物と成ることがある。

平成 2 年から渡良瀬遊水地では、毎年 2 月上旬から 3 月下旬までの約 1 ヶ月半間、「干し上げ」を実施している。干し上げとは、谷中湖の最低水位 (Y.P.+8.5m) よりさらに 20cm 水位を下げて湖底面を露出させ、一定期間日光にさらすことにより、カビ臭発生の原因と考えられる植物プランクトンなどを死滅させることによって、水道用水の水質の保全を図れる。

6 月と 8 月に Acanthoceras zachariasii を検出され、密度は 47inds/ml と 1inds/ml であり、9 月と 11 月に検出されなかった。6 月には珪藻、緑藻の成長が比較的に旺盛であり、温度の上昇に伴い珪藻の一部の種は抑制され、9 月に入って高温に耐える緑藻と藍藻の数量が増加し、優占藻門となった。窒素、リンなどの栄養塩の増加、藍藻類の大量成長、さらに水質悪化は渡良瀬遊水地の水質を貧栄養化から栄養化に移行させ、貧栄養を代表する指示生物 Acanthoceras zachariasii が生存不能となり減少した。

3.4 藍藻類の個体群密度変化

Microcystis 属の藍藻類は最もよく見られる藍藻類アオコを誘発できる浮遊藻類であり、その産生する Microcystis 毒素は藍藻類アオコ中の出現頻度が比較的に高く、非常に危害を及ぼす 1 種類の藻毒素であり、Microcystis の形成過程と産生する藻毒素に対する研究は国内外で多くの研究報告がある[10]。

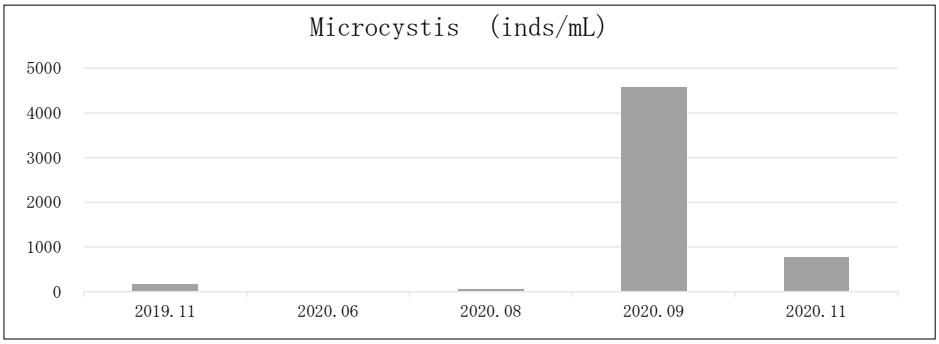

図3.5　Microcystis密度変化

渡良瀬遊水地では毎年湖床排水を行っているが、6月は水質が非常にきれいで有毒なアオコは出現せず。水温の上昇に伴ってアオコ濃度が著しく上昇し、9月にはアオコ濃度が最大値に達した。そのため、水温が高い季節にはアオコの発生リスクが高くなる。

渡良瀬遊水地は給水として水質安全の問題が極めて重要であり、アオコ産生藻類がアオコ毒素を水体内に放出することは、受水区住民の水の安全を大きく脅かすことになる。 そのため、藍藻類の生長が盛んな季節に、藍藻類の個体群の動態変化に対するモニタリングを強化し、特にフィオトキシンを産生する藍藻類の分布状況に注意し、それを早期に制御し、藍藻類の毒素放出のリスクを減少させるべきである。

４．結論

本研究では、緑藻門（Chlorophyta）、藍藻門（Cyanophyta）、珪藻門（Baillariophyta）とクリプト藻門（Cryptorhyta）の種類について統計を行った。

データに基づいて、藻類密度、Shannon-Wiener(H)種多様性指数、Margalef(D)種豊富度指数、Pielou(J)均一度指数、Simpson(d)多様性指数、群落構造などの植物プランクトンの群落特性と指標が、渡良瀬水域の富栄養化状態を評価した。渡良瀬遊水地が2019年11月にVI類水質貧栄養化状態、2020年6月にV類水質貧－中栄養化状態、2020年8月、9月、11月ともにIV類水質中栄養化状態にあることを示している。

調査期間中、5回のサンプリングで計4綱45属88種（変種、変形を含む）の浮遊藻類が同定された。その中に緑藻門19属41種があり、占める割合が最も大きく、珪藻門19属35種、藍藻門6属7種、クリプト藻門1属1種であった。渡良瀬遊水地種群属構成でも種類でも緑藻－珪藻－藍藻型であることが示唆された。

渡良瀬遊水地藻類の同定では、浮遊藻類の存在を示唆するものもいくつか認められ、水質の貧栄養化を代表する珪藻subacanthoceras zachariasiiの存在は、6月と8月には検出され、9月と11月に検出されなかった。6月以降は藍藻類の大量成長により水質が悪化し、渡良瀬遊水地の水質は貧栄養化から栄養化へと移行し、貧栄養を代表する指示生物Acanthoceras zachariasiiが生存不能となり減少した。

植物プランクトン群落多様性と群落構造が8月で不健康な状態である。藍藻類の割合が過大で、全窒素、全リン、COD（化学的酸素要求量）を参考に、プランクトンを指示種として有効な水質評価を行っていることを示した。

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OVERVIEW OF THE LOCALIZATION OF RENEWABLE ENERGY TECHNOLOGY IN INDONESIA:

TYPES, BARRIERS, AND OPPORTUNITIES OF THE IMPLEMENTATION

Deanty Mulia Ramadhani, Masachika Suzuki

Abstract

Indonesia is expected to achieve the national target of renewable energy use by up to 23 percent by 2025. Multi-sectoral efforts and collaborations are encouraged to pursue this target since renewable energy transition requires the roles of multi-stakeholders and institutional arrangements at any levels. The objective of this article is to overview the development of community-based renewable energy transition in Indonesia, particularly small hydropower (SHP) and solar PV projects. It identifies the development of the implementation types of energy transition at the local level, what the barriers or challenges faced during the transition process, including the potential opportunities emerging from the localization of renewable energy transition process, particularly in hydropower and solar PV, where remote areas and islands in Indonesia have huge potentials within them. The research illustrated in this article used two main research methods consisting of literature and policy document reviews and stakeholders' interviews. This article addresses an inter-disciplinary approach in the context of community participation in rural energy transition process.

インドネシアにおける再生可能エネルギー技術のローカリゼーションの概説：

技術導入の種類、障害、可能性に関して

デアンティ ムリア ラマダニ・鈴木　政史

要約

インドネシアは2025年までにエネルギー構成における再生可能エネルギーの割合を23%まで引き上げることを国家目標に据えている。この目標の達成に向けた再生可能エネルギーの導入には、様々なステークホルダーと制度的な調整が求められると同時に多くの分野の協力と協働が求められる。本論文は、インドネシアにおける小水力および太陽光発電のコミュニティーベースの再生可能エネルギーの移行・発展を概説する。遠隔地域や島嶼部におけるこの二つの発電形態のローカルなレベルのプロジェクト実施の種類、実施における障害、潜在的な可能性を示す。先行文献のレビュー及びステークホルダーへのインタビュー調査を通してこのテーマに取り組む。また、学際的なアプローチを通して遠隔地域のエネルギーの移行プロセスにおけるコミュニティーの役割を検討する。

OVERVIEW OF THE LOCALIZATION OF RENEWABLE ENERGY TECHNOLOGY IN INDONESIA:

TYPES, BARRIERS, AND OPPORTUNITIES OF THE IMPLEMENTATION

1. Introduction

Indonesia is expected to achieve the national target of renewable energy use by up to 23 percent by 2025. Multi-sectoral efforts and collaborations are encouraged to pursue this target since renewable energy transition requires the roles of multi-stakeholders and institutional arrangements at any levels. In respond to synergize the Paris Agreement and 2030 agenda, in which to increase the affordability of clean energy (SDG #7) and intensify climate actions (SDG #13), Government of Indonesia (GoI) aligns the national energy policy with Nationally Determined Contribution (NDC) with the involvement of, not limited to national and local government, also non-state actors, for instance NGOs and private sectors. Several strategic national plans to reduce the emissions to 29 percent by 2030 in sub-sectoral approaches are taken by GoI. Policies and programs on energy sector through the implementation of clean and renewable energy transition is asserted as one of the national mitigation measures on NDC and implemented under the Presidential Regulation Number 71/2011[1]. The development of renewable energy sources, such as solar PV, wind turbine geothermal, biogas, biomass, and hydropower for electricity production is taken into consideration as an approach to meet an ambitious national energy mix target (See Figure 1). Despite of the largest contribution of oil and coal in the total energy mix, Figure 1 shows the slight rise of new and renewable energy supply percentage from 2019 to 2021.

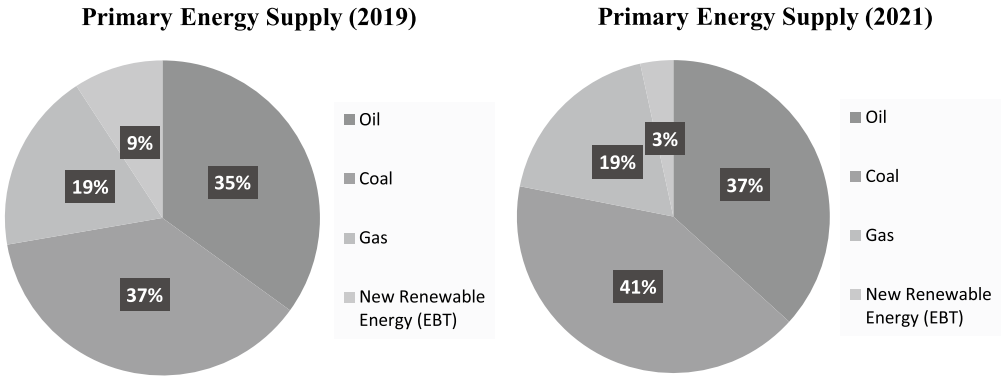


Figure 1. Primary Energy Supply of Indonesia (2019) and (2021)
(Source: Handbook of Energy and Economic Statistics of Indonesia, 2021)

As Indonesia has abundant renewable energy sources, the GoI believes that clean energy could be a solution to decrease the discrepancy of energy access and affordability between urban and remote areas. In order to promote renewable energy transition for energy security and affordability particularly in rural and remote areas, the GoI has stipulated several policies and regulations related to clean and renewable energy utilization through commercial and non-commercial power plants[2]. Missing the 23 percent target of

national renewable energy in the energy mix is an eye-opening notice for the GoI to be committed to a market expansion and investment acceleration of renewable and clean energy in Indonesia despite of its abundant resources and current policies existence. Not limited to the GoI, the role of private sectors, both foreign and domestic investors, is also imperative to improve the feasibility and sustainability of the smart-grid projects in Indonesia. The GoI is required to create an investor-friendly with considerably less-risky market atmosphere and predictable regulatory system[3]. In this way, the investors could have more confidence to do investment in a settled market system. On the other hand, it is important as well for the private investors to take into account and align with the principles of renewable energy business opportunities set by the GoI which include (1) the local content requirement and (2) investment and ownership restrictions. The characteristics of energy market in Indonesia should be identified and recognized by the relevant involved actors, in particular private investors to successfully develop smart grid transition projects in Indonesia. Creating inclusivity and viability within the project are two main points that has to be necessarily taken into account.

As mentioned above, the GoI claims that they have enacted supporting policy regulations related to clean energy transition acceleration through business and investment opportunity. In 2000, the GoI reformed energy regulatory body from the Ministry of Mines and Energy to the Ministry of Energy and Mineral Resources (MEMR) and re-defined national energy dominant polices. The commitments of the GoI to clean and renewable energy development target and priority are incorporated into the National Energy Plan (*Rencana Umum Energi Nasional* or RUEN)[4]. According to MEMR, hydropower, bioenergy, and geothermal play primary and substantial roles in clean energy development in Indonesia which the installed capacity of each account for 4,826 MW, 1,438 MW and 1,671 MW respectively (See Table 1)[5]. In developing country, such as Indonesia, financial, and economic feasibility becomes an important

Table 1. New and Renewable Energy Potential Capacity

No.	Type of renewable energy	Potential capacity (MW)	Installed capacity (MW)	Percentage use (%)
1	Geothermal	29,544	1,438.5	4.9
2	Hydropower	75,091	4,826.7	6.4
3	Mini-micro hydro	19,385	197.4	1.0
4	Bioenergy	32,654	1,671.0	5.1
5	Solar	207,898 (4.8 kWh/m2/day)	78.5	0.04
6	Wind	60,647 (±4m/s)	3.1	0.01
7	Sea wave	17,989	0.3	0.002

Source: MEMR (2017)

determining factor to install renewable energy technology. In that case, hydropower is considered as a cost-efficient technology option compared to others in terms of the construction, installation, operational and maintenance with the minimum payback period around from 1 to 6 years[6][7][8].

On the other hand, solar PV which has the largest potential capacity (207,898 MW) accounts for less than 100 MW and smaller compared to other installed renewable energy sources in Indonesia. Despite of the small number of the installed capacity, MEMR targets to optimize solar PV installation through developing two types of solar PV, which consist of solar PV ground mounted and rooftop solar PV[9]. According to RUPTL, the GoI under the PLN, as a state-owned electricity company in Indonesia prioritizes the development of solar PV named centralized PV for electrification acceleration in rural and remote areas where the national grid is not accessible. The decreasing cost installation of solar PV at the global market influences the solar PV deployment, both on- and off-grid technology appears to be more potentially competitive and prominent in Indonesian energy policy targets[10]. Despite the abundance of solar energy potential, as Indonesia is located nearby equator line with sun lights along the year, the GoI still has difficulties in achieving national target of the installed solar PV technology according to the National Energy Planning (RUEN). The geographical advantage that Indonesia owns is not conformable to the government capacity to manage renewable energy sources into worthwhile clean energy technology.

Despite those identified advantages of hydropower and solar PV technology as clean energy, in the aim of installation, the GoI prioritizes more on the development of small scale and micro-grid technology (SRETs) rather than the larger ones, especially in the rural, remote and island areas. In terms of the sustainability risk aspect, large hydropower could expose effects to the safety of aquatic biota biodiversity and the water quality[6][11]. Although there is still no absolute agreed definition of small-scale hydropower that is scientifically proved, a maximum of 10 MW is the accepted installed capacity of micro-hydropower scale[12]. This case also applies to solar PV technology where the government's ambition is primarily focused on developing small scale distribution and off-grid solar PV networks to be deployed in the rural area settings[13]. Small scale renewable energy technology might fit to the developing countries such as Indonesia. From the economic and environmental points of view, it is more cost-efficient, less adverse effects to the environments, and more feasible in decentralized management. The implementation of small-scale renewable energy in rural and remote areas might have advantages for the local people to increase the energy supply. However, at the same time, it also could be challenging for the government to have good practices and find the right actions in the implementation and management that involves multi-stakeholders, such as private sectors, investors, non-governmental organizations (NGOs), regional government, local community, and others, with multiple interests.

Various schemes of renewable energy technology deployment have been implemented in Indonesia. For instance, the GoI has set strategies and regulations to increase the renewable energy infrastructure in Indonesia to optimize the energy supply in the rural and remote areas. However, the implementation is conducted in various business schemes, particularly when it comes to rural community which has the influence to the transition process. Therefore, this article overviews how clean and renewable energy transition process is localized following the distinctive inherent characteristics of each rural area and community. This study identifies the development of the implementation types of energy transition at the local level, what the barriers or challenges faced during the transition process, including the potential opportunities emerging from the localization of renewable energy transition process, particularly in hydropower and solar PV, where remote areas and islands in Indonesia have huge potentials within them.

2. Literature Reviews

2.1 Energy Policy Framework in Indonesia

In terms of the energy sector, Indonesia has set of specific regulations stipulating national energy policy, which is called as National Energy Policy (*KEN: Kebijakan Energi Nasional*). This regulation is recognized as a set of national fundamental energy policy framework that refers to Energy Law No. 30/2007. According to this law, it enacts that government is responsible to guarantee the energy supply to the community, efficient, optimum, and sustainable energy sources management, and provide subsidy for poor community groups, and international. In Article 17 and 18 under the Law No. 30/2007, the national government is obliged to involve regional government and take into accounts the opinions and inputs from the local community[14]. The roles of the community in the national and regional energy strategic planning are imperatively mentioned within the law. In Article 23, it is also mentioned that energy exploitation services can be carried out by the business entity, permanent establishment and individuals comply with government regulations. It depicts that energy supply services and management requires varies of stakeholders, not limited to governmental actors, also non-governmental ones. Based on this law, President of Indonesia formed the National Energy Council (*DEN: Dewan Energi Nasional*) to formulate national energy policies stipulated by the government with parliament members' approval and supervise the energy policy implementation. Table 2 summarizes the contents of Energy Law No. 30/2007.

Table 2. Summary of Energy Law No. 30 / 2007

Articles	Contents
Article 3	Guarantee of stable energy supply
Article 4	Control and regulation of energy resources carried out by the government
Article 5	Guarantee of national energy reserve
Article 7	Provision of subsidy fund for poor community groups by national and regional government
Article 9	Government is obliged to encourage local content requirement in energy management
Article 12	National energy council establishment
Article 17	The involvement of regional government
Article 19	The roles of non-governmental actors, including individual community or groups
Article 21, verse (1)	Utilization of new and renewable energy that considers sustainability aspects and prioritizes the energy needs and economic activities at the energy resource areas.
Article 21, verse (3)	Facility and or incentives from national and or regional government for utilization of new and renewable energy conducted by business entity, community group or individual.

Source: Constructed by the author

As mentioned above, the KEN is the fundamental Indonesian energy planning policy. The KEN was signed and stipulated by the President of Indonesia under the Government Regulation (*Peraturan Pemerintah* No. 79/2014). This government regulation is established to carry out Law No. 30/2007 regarding the energy policy

implementations. The KEN provides directions on management of energy independence and supports the energy development compiled as a guide for national energy security. Within this PP No. 79/2014, there are also some articles that promote the involvement of non-governmental actors from cross-sectoral and level organizations in the national energy management. In Article 23 verse (1), it is mentioned that the development and strengthening energy access and the infrastructure is carried out by the national and or regional government. However, in the following verse (2), it clarifies the previous verse that the development and strengthening energy access and infrastructure is conducted in several ways, and one of them is providing the access to and facilitating community in gaining energy-related information in transparent and accessible ways. In the article explanation of PP No. 79/2014, the GoI also acknowledges that energy-related problems in Indonesia is not limited merely to the lack of energy infrastructure and national budget, but also the energy management has not fully implemented the principles of the sustainability[15]. Table 3 summarizes the main content of PP No.79/2014 that is related to the energy localization and the involvement of the non-governmental actors.

Table 3. Content Summary of PP No. 79/2014

Article	Contents
Article 3, verse (1)	National energy policy consists of 2 (two): main policy and supporting policy
Article 3, verse (3)	Supporting policy complies the energy diversification, subsidy and incentives, infrastructure and energy access for community, technology development and funding
Article 6	Promoting energy management independence and fair and equitable access for community
Article 9	Increasing the energy mix with 23 percent of renewable energy by 2025 and minimum of 31 percent by 2050

Source: Constructed by the author

Table 3. Content Summary of PP No. 7o/2014 (Cont.)

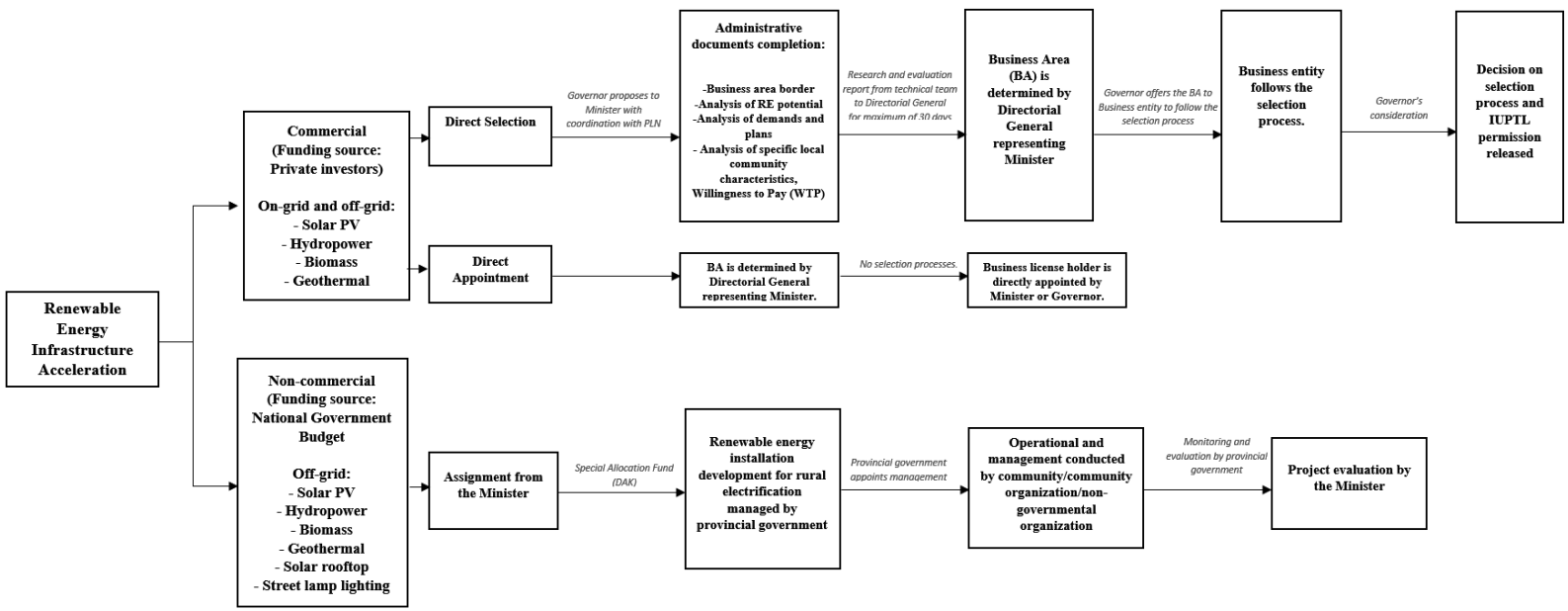
Article	Contents
Article 11	Energy development prioritizes utilizing local energy resources
Article 12	Renewable energy sources from hydropower and geothermal are utilized for electrification; and solar is for electrification, industrial, transportation, and household sectors
Article 20	Government controls renewable energy market, including minimum quota of electricity sourced from new and renewable energy
Article 22 verse (1)	National and regional government provides fiscal and non-fiscal incentives for renewable energy diversification
Article 22 verse (2)	Incentive provision for the development, business, and utilization of small-scale renewable energy located in remote and rural areas
Article 23	Acceleration of new and renewable energy infrastructure provision and convenient access to community
Article 26	Regionalization of electricity energy supply to areas outside Java Island

Source: Constructed by the author

Another policy instrument to support the development of new and renewable energy in Indonesia is Presidential Regulation (*Perpres*) No. 112/2022. This regulation is enacted to accelerate renewable energy transition development across Indonesia and increase the energy investment[16]. This regulation explains about the position and role of *Perusahaan Listrik Negara* (PLN), the owned-state electricity company, as the most authorized institution to conduct sale and purchase agreement and formulate RUPTL which contains the procurement, transmission, distribution, and/or sales of electricity power business to the consumers. However, based on Ministerial Regulation (*Permen* ESDM) No. 53/2018, PLN is diverted to become a limited liability company or *Persero.* Within *Perpres* No.112/2022, it regulates that if the power plant is established by private business actors, renewable electricity energy procurement pricing consists of 2 (two) methods, (1) the rooftop benchmark price, (2) deal price, with or without considering the factor of location. The rooftop benchmark pricing applies for hydropower and solar PV. In order to strengthen the electricity supply system, PLN in this case can buy the excess power from the business license holder that utilizes renewable energy sources. If the power plant is established wholly or partly by government or regional government, including grant project, the procurement pricing applies the rooftop benchmark price for all power plant capacities. The power procurement process owned by business entity is carried out by 2 (two) methods; direct appointment and direct selection. Those processes are conducted under the authority of PLN. The decision of power procurement methods depend on who holds the business license holder (IUPTL)[17]. The Direct appointment method is applied if the power purchase comes from hydropower that utilizes dam or irrigation channel owned by the government, including the capacity expansion from solar PV. On the other hand, direct selection is carried out through the lowest prices offer based on the rooftop benchmark price and conducted in transparent and fair without giving privilege to any party. The power procurement process applies different methods if the power plant is established by governments or considered as the grant project. This project is included as non-commercial power plant project, which the goal of the energy infrastructure development is located in rural, remote and island areas of Indonesia.

The GoI, under MEMR, also has enacted the Ministerial Regulation No. 38/2016 regarding the acceleration of rural electrification in remote areas and isolated islands through utilization of small-scale renewable energy development. This regulation is to manage electricity supply in a small scale with maximum total capacity of 50 Megawatt (MW). In the case of non-governmental-owned power plant, GoI has set regulation PP No. 25/2021 which one of the main points is about Business Area (BA). According to the regulation, one business area is undertaken by merely one business entity, which could be government, private business holder, including local cooperatives. This policy provides wider opportunity of participation in electrification acceleration for multiple stakeholders, from governmental to non-governmental institutions. Wide policy instruments are existed to differentiate various types of renewable energy electrification business model in Indonesia, including regulating the depth of non-governmental actor participation within the transition process. Figure 2 summarizes the administration and regulatory process with regards the renewable energy infrastructure development acceleration according to the national policy instruments and regulations.

Figure 2. Renewable Energy Business Pipelines



Source: Analyzed by the authors

Generally, the government strategy in accelerating renewable energy infrastructure development consists of 2 (two) aspects, which include (1) commercial and (2) non-commercial renewable energy projects[18]. Figure 2 depicts that either commercial or non-commercial energy project, the aspect of community is considered within the process. However, the extent to which the involvement of community within the transition process is not explained further yet. According to Ministerial Regulation No. 36/2018 with regard to Operational Guidelines of Special Allocation Fund (DAK) Implementation on Small-scale Energy Sector, government strategy in renewable energy acceleration is focused on funding physical installation through DAK to those rural and remote areas where electricity access is not available yet. The renewable energy power plants primarily focus on micro-hydropower, solar PV (floating and centered), biogas, including the revitalization of micro-hydropower and solar PV. In the context of hydropower and solar PV installation, regional government is authorized to designate an organization to conduct the operational and management of power plant installation, including community organization. According to Ministerial Regulation No.38/2016.

On the other hand, in the commercial aspect which the funding source is mainly from the private sectors, GoI also enacts regulations through Ministerial Regulation No. 38/2016, No. 53/2018 with regard the acceleration of the small-scale rural electrification. Despite the business license holder is handed over to the private actors, the participation of community is also taken into account within the transition process in various agreed business model. During the administrative process, community characteristics are identified prior to install the power plant in the area. Through the regulations, the GoI encourages the establishment of the community engagement between the private actors and the local community where the energy transition project is installed.

2.2 Current Stage of Localization of Clean and Renewable Energy Transition in Indonesia

As an archipelago and tropical country, Indonesia has abundant natural resources of water and sunlight along the year. It is expected that with those rich domestic natural resources, Indonesia is able to meet the energy and electricity demand at the national level. Contrarily, the utilization of solar PV and hydropower have not been optimal yet. The share of new and renewable energy in total energy mix of Indonesia approximately reaches 12 per cent by 2021 with hydropower becomes one of the most substantial utilized renewable energy sources which accounts for 3 per cent[19]. On the other hand, solar PV contributes for 0.05 per cent of the total energy mix of Indonesia by 2021 with slight increase per each year. Those numbers show that the utilization of renewable energy sources is not growing side by side with the potential of the available natural resources. Nevertheless, there is still no previous literature mentioning the significant influence of renewable energy potential availability to the ability of meeting the electricity energy demand. In this case, the availability of natural resources for renewable energy utilization has to take the good[20] practices and sustainable management into consideration, including who controls the operational and management, who the actors are involved, and how those relevant actors are interconnected, including the existed regulations and supporting policy enacted by the government to rule the implementation. The role of local communities and non-governmental organizations is the key aspect in building a sustainable and reliable system for renewable energy development in Indonesia.

There are numerous of theoretical frameworks used to identify the involvement of community in energy transition in different ways of aspects. The concept of 'community' has a wide-range of ways and is challenging to define, in which it is notable to consider the sizes, levels, and process of social norm development to have community engagement[21]. The 'community' term has been tailored to the energy sector and emphasized with the emergence of community energy. A number of studies show a significant intercourse between ownership scheme and the implementation process of decentralized community energy projects[22]. Ownership was identified as one of the determinant aspects to increase the participation of local communities, particularly in rural areas[23]. However, little of them explores the extent to which degree of participation of the community in particular ownership models in energy transition projects. The rationales for local community engagement within the renewable energy project might be encouraged by the expected outcomes from the project to multiple stakeholders[24], mainly by the financial issues which is considered as a primary contributing factor in successful low-carbon energy initiatives[25]. In the community-based energy project, community participation depends on agreement and contract which the involved actor's community agree, for instance community energy project in Europe emphasizes not limited to social inclusion, but also financial inclusions, which local community organizations invest and run the project[26]. Therefore, the implementation of ownership model in community energy can be varied in terms of arrangements, structures, and level of inclusivity. In addition, willingness of community to participate is also connected with the extent to which participation level is opened and accessible for community. Social expectations, for instance, can be an important aspect which influence the community expectations and participation roles which the locals want to involve[23].

2.2.1 *Badan Usaha Milik Desa (BUMDes)*

Generally, regional governments also have responsibility in ensuring the energy supply to the regional and village areas of Indonesia. One of the responsibilities of the regional governments is depicted in the Regional Energy Planning or called *Rencana Umum Energi Daerah* (RUED). In order to attract the interest of external investors and boost community involvement, it is necessary for them to provide a business model that is not only investor-friendly, but also reliable and appropriate for local customs and characteristics. Community-based energy projects have been expanding widely, particularly in rural and remote areas of Indonesia. Community participation is an imperative factor to influence the success of renewable energy power plant operational and management[27]. Promoting the establishment of community autonomy in management of small hydropower (SHP system, such as local cooperative (*koperasi*) and local business entity or *Badan Usaha Milik Desa (BUMDes)* is one of the ways to involve local community within the renewable energy transition process in rural and remote areas. GoI regulates the role of *BUMDes* in Presidential Regulation (PP) No. 11/2021 which defines *BUMDes* as a legal entity established by the village or together with villages to manage business, exploit assets, develop investment and productivity, providing services and/or providing types of business for the greatest welfare of villagers[28]. Through decentralized scheme of renewable energy technology, it could stimulate business opportunity and increase the job employment for local community[29]. The business unit can vary from economic to public services that are managed independently by the organization.

2.2.2 *Local Cooperatives (Koperasi)*

Local community is mostly represented by locally or village organized cooperative, which is commonly called as Electricity Cooperative (*Koperasi Listrik Pedesaan/KLP*)[30]. Despite of significant role of local cooperatives in rural electrification program, not only providing social participation, but also aiming to increase the business opportunity and economic benefits for local community, it is often left behind during the development process. Whereas, in order to increase four main indicators of energy security (availability, accessibility, affordability, and acceptability), energy policy and infrastructure development are not adequate yet to improve the energy security. As social and cultural transition can only be driven through structural changes and collective values and awareness, the role of village cooperatives is necessary as an institutional instrument at the local level[31]. Indonesia is a country where the cooperatives have significant role and influences to the economic growth, particularly in the villages and rural areas[32]. The GoI has enacted Law No. 17/2012 and supporting Government Regulations No. 7/2021 regarding the cooperatives. According to those regulations, the local cooperatives get access to Special Allocation Funds (*Dana Alokasi Khusus*) from the national government to business activity empowerment and development, including electricity energy provision for the interest of the local people. The International Labor Organization (ILO) also promotes that local cooperatives can significantly contributes to the rural electrification acceleration, either in developed or developing countries[33]. Based on Law No. 30/2009 about electricity, not limited to private actors, but other non-governmental organizations, such as the cooperatives or community organizations are allowed to involve in electricity supply business[34]. The form of participations of local cooperatives could be various depending on the power plant capacity, from building partnership with private developers to owning the power plant[35].

2.3 Community-based Hydropower Development

According to the data from MEMR (2016)[36][37], Indonesia has approximately 75 GW large hydropower and 19 GW small hydropower potentials. However, only around 9 per cent of the total potential is installed into the large hydropower power plant[24]. Besides the abundance of hydropower resources potential, GoI also has been encouraging the development of hydropower in Indonesia, particularly in rural and remote areas due to its safety and less risk. A wide range of study have previously mentioned that hydropower is widely known as one of the most significant advantages renewable energy technologies with lower cost and risk yet high reliability which might be compatible for rural condition[38][39]. In particular, small hydropower (SHP) is regarded as one of the reliable renewable technologies to expand the participation of local community and self-sustainability in rural energy transition. Imo et al. (2019), for instance, analyzed that small hydropower technology, which is less risky and complex compared to the large one, gives impact to rural and remote community, especially in driving the economic and social benefits to the dwellers.

Community-based business models in SHP development in rural have been evolving around the world. Some previous studies have identified several case studies of micro hydropower across the world that provide business opportunities for local community to involve, not limited as the user or the consumer, but also as the owner, the investor and or the management. Alam et al. (2021) studied a case study of community-

based SHP in rural areas of Miyazaki prefecture in Japan. Their research identified the constructed business scheme within SHP where independent community cooperative is purposively established to build business operational and management at the local level. The study found that community manages from the upstream to the downstream of SHP development, without the intervention of external stakeholders, such as government and private sector. According to this study, this type of a community-owned SHP business model is acknowledged to provide an opportunity for the local dwellers to build more reliable and sustainable system of SHP as the technical and organizational aspects are taken care by the local community, in this case the local cooperative as the business management. In Nepal, community owned and managed-hydropower is also considered as a renewable energy technology that fits to the needs and local dwellers and geographical characteristic, particularly producing multiplier effects to agricultural household productivity[40]. Koirala et al. (2019) concluded that renewable energy development that positions community as the owner and management could aim to reduce the poverty at the local level. The electricity tariff is also mutually agreed by the local community as the owner and the users at the same time. In addition, besides community-owned SHP, community ownership also embodies in co-owned SHP business model in which the community collaborates with either government or non-governmental actors. El Bote SHP, for instance, located in North-Central Nicaragua is also another example of how community initiative based renewable energy project with co-funding sources is built and managed by the local dwellers. According to the report of the United Nations Industrial Development Organization and the International Center in Small Hydro Power [2019], El Bote SHP was established using a combination of private and public funding sources and bank loan for the construction. This report depicts that co-ownership model of SHP could increase the efficiency and quality-service of the technology. Through collaboration in funding and management, the potential risk and burden of maintenance could be shared with the private sector as well.

2.4 Community-based Solar PV Development

Solar PV has been rapidly developed as one of the alternative renewable energies in rural areas in Indonesia. In order to foster the implementation of Solar PV transition in rural areas, the concept of localized business scheme has been promoted as one of the tools to elicit inclusive community participation and pave the way for community in business opportunities through a co-ownership energy model. Through the co-ownership scheme, community participation is expected to be executed in a concrete form and inclusive program, not merely limited to social participation, also financial inclusion. It is expected to increase community participation in rural energy development and encourage provision of community benefits. Indonesia has increased its off-grid solar PV installed capacity for approximately 6% in a year from 2021 to 2021, with private production (owned by private or non-PLN) accounts for around 114 GWh, more than production owned by PLN (6 GWh) in 2021 (BPS, 2021). This number is away from the national target set by GoI through the national Energy General Plan (*Rencana Umum Energi Nasional,* RUEN) 6.5 GW of solar power installed capacity[41]. Even though, solar power is considered as the largest source Indonesia has, which accounts for 208 MW compared to other renewable energy sources in Indonesia (MEMR, 2021). GoI steps up the ambition to achieve the national target of installing 1000 solar PV projects focused in rural, remote

and island areas. This program is devoted to the areas of Indonesia where face the drawbacks on electricity expansion and unreachable network access from PLN. The off-grid mode is regarded as one of the win-win solutions for rural electrification considering the distance of rural and remote areas from the national grid. Wide range of studies analyze pertinent the development of solar PV in Indonesia, particularly discussing the potentials and the roadblocks of the installation. Hamdi (2019) identified the policy dynamics which influence the solar PV development in Indonesia[42].

One of the issues that GoI has to pay attention to is aligning the human resources capacity and skills to go along with the energy infrastructure development. Another core issue in accelerating the potential of renewable energy development in Indonesia is also the national energy-related regulations mandated by the GoI which tend to extend the bureaucracy process of the energy installation[43]. The complexity between the institutional context and the human resource issue hinders the acceleration of energy transition in Indonesia. Regarding the potential capacity, solar PV is recognized as one of the largest renewable energy alternative sources in Indonesia. It is taken into account by GoI as an efficient, low emission-produced energy sources and win-win solution to rural and remote electrification. On the other hand, the installed capacity of solar power plants is far away reaching from the national target mandated in RUPTL by MEMR. High-cost solar PV investment and maintenance is one of the drawbacks of the solar PV expansion. Modjo (2019) criticized the GoI priority in solar PV acceleration is inverse with solar PV-related policy and regulations mandated by GoI. He mentioned that according to RUPTL 2019-2038, solar PV planned capacity is targeted at 207,898 MW of 127 GW as the total capacity needs in 2025. This number indicates that PLN primarily rely on solar panel installations for increasing solar PV installed capacity, while commercial solar PV mini-grid is not prioritized yet. In this case, MEMR requires private collaboration and investment to boost solar PV development in Indonesia, not merely limited to on-grid large solar PV, but also mini off-grid scale and encourage solar panel installation for residential and business buildings.

3. Research Methods

The objective of this article is to overview the development of community-based renewable energy transition in Indonesia, particularly SHP and solar PV projects. This study used 2 (two) main research methods which consist of: (1) literature and policy document reviews and (2) stakeholders' interviews. This article affords an inter-disciplinary approach in the context of community participation in rural energy transition process. This article builds on data collection and review analysis of existing relevant literatures on community-based renewable energy, in particular with regard to solar PV and SHP. The review includes reports, presentations, articles, policy documents, evaluation and monitoring documents, published or non-published documents and literatures issued by the government[44] as well as scientific institutions that captures the development of community-based solar PV and SHP projects in Indonesia. The study focuses on policy document and literature review analysis, as the other previous studies overview the energy community, its evolution and transition process[45][46][47]. Subsequently, this article also collects policy instruments-related documents from municipal authority to analyze and understand to what extent

policy and regulation dimensions have been reaching out the development of the localized renewable energy transition in Indonesia, particularly small-scale projects that involves local community and local institutions.

All the chapters of official governmental policy documents are identified and summarized into several main points which explain the development of community energy, including the determinant factors and aspects that might influence the policy implementation. To measure the validity of this overview, this study merely considers studies (journals/papers/articles) that are undertaken by scientific institutions or public authorities. Through conducting initial review of policy papers and relevant scientific journals and documents, the authors include the papers with at least one contribution found by the keyword for *community energy* or *energy community.*

The second step of this study methods is conducting semi-structured interviews adopting snowball sampling as the method of stakeholder's selection. The objective of the in-depth interview aims to illustrate how the development of community energy at the level of implementation, from the business scheme, the involved relevant stakeholders, the existed barriers and the potential opportunities. The goal of the stakeholder interviews is to perceive to what degree the policy instruments and regulations are executed and influence the implementation of the community energy. The interviewees cover non-governmental organizations and private sectors, including the local cooperative, private donor, and the local business entity or known as *BUMDes* in Indonesia. The last step is to conduct analysis on business model canvas. In order to aim visualizing various business models implemented in the localized community energy project in Indonesia, business model canvas is used as a mapping tool to identity a wide range of constructed community-based energy business models in Indonesia, particularly in rural areas. The business canvas model helps to generate the potential business models in the field of renewable energy sources[48]. It also directs to identify the existing business models and generate other potential business models[49]. Figure 3 summarizes the structure of research presented in this article.

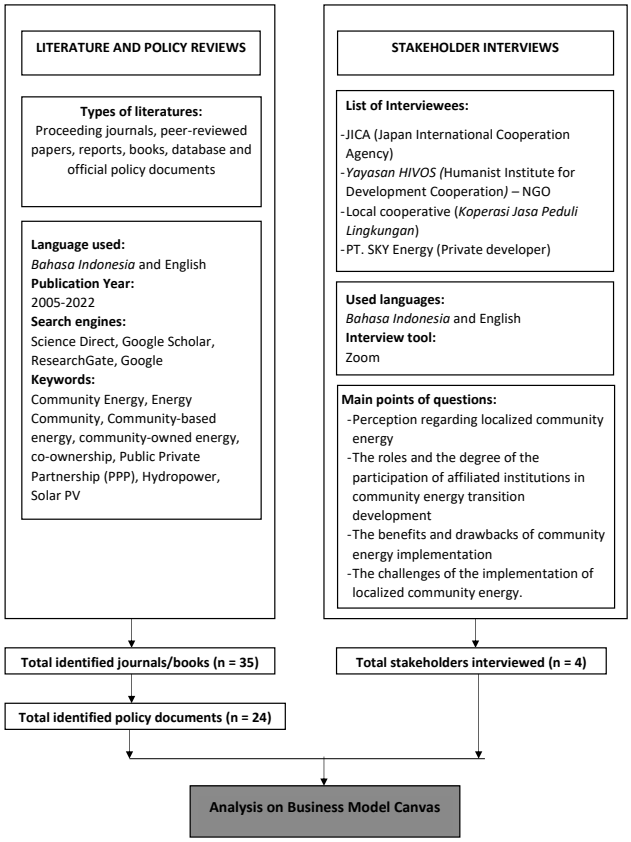


Figure 3. *Systematic review on community energy in Indonesia constructed by the authors*

4. Results and Discussions

This section outlines the result and discussions which comprise 3 (three) parts; the types of community energy in Indonesia, the barriers and the opportunities of energy community practices in Indonesia.

4.1 Constructed Types of Community-based Energy in Indonesia

Despite of multiple interpretations regarding the terms of community energy or energy community or localized energy, this article identified the relevant journals and policy documents of Indonesia and sum up the '*constructed' definition of community energy* that is implemented in Indonesia. The community energy followed with the constructed term depicts that the embodiment of the localized community energy might lead to various practices and forms of partnership in different areas and cases. According to the stakeholder's interviews, most of the interviewees, both from private donors and local community cooperatives agreed that a project is properly defined as localized energy transition project when community (including the community organizations and cooperatives) is the main actor within the process, either it is community- or private and government-initiated project. The geographical condition and community characteristics primarily raise the distinctive on business models and partnership implemented within

the localized energy projects. However, theoretically and practically, the role of locally-organized business entity and cooperatives play major positions and influences the extent to which the community energy can possibly implemented in reliable and sustainable ways. According to the collected data, there are basically two types of identified localized community energy in Indonesia. First, community-owned energy where the transition initiatives primarily come from the local community itself. Using business model canvas, the author documented how the community-fully owned energy project is implemented. The roles and influence of national government, in this case MEMR and Ministry of Villages are not that significant since the local community mainly controls the transition process, from the installation to operational and management. One of the interviewees on this study from the representative of the local cooperative, mentioned that the benefits of this scheme of localized energy is the community is not necessary to deal with complex government administrative bureaucracy. The highlight of this business scheme is that the locally managed business entities take a control in the energy financing management, including making estimations on the nominal of dues, the profits and revenues. The role of private actors is limited to providing the funding or grants to the community-initiated energy projects. They have finite authority on operational and management of the renewable energy supply projects.

The second identified type of the localized community energy is co-owned energy projects. This type of community energy model basically involves local community and other relevant stakeholders, which could be private sectors and/or local governments. The role of community is not as strong as in the community-owned energy scheme. The key partners are similar to the previous business scheme. However, PLN has the obligation to procure the electricity produced by the power plant producers if the capacity is less than 10 MW, including the excess power supply by cooperatives[50]. If we take a look back at the identified policy documents issued by the GoI, Indonesia has basically provided a wide space for the local entities and communities to directly involved in community energy transition in rural areas. The birth of policy instruments that governs the community initiative of energy projects and decentralized energy project managed by local cooperatives, such as Law Presidential Regulation (PP) No. 11/2021, Law No. 17/2012 and supporting Government Regulations No. 7/2021 have shown the commitment of national government to boost energy independency through localized energy system in rural areas and attract private donors or investors to collaborate with local communities. Those regulations stimulate the evolution of types of community energy practices in Indonesia, especially in rural areas, where local community and cooperatives become the initiator, owner, including the operator and manager. Figure 4 and 5 separately summarize business model canvas on two different types of projects.

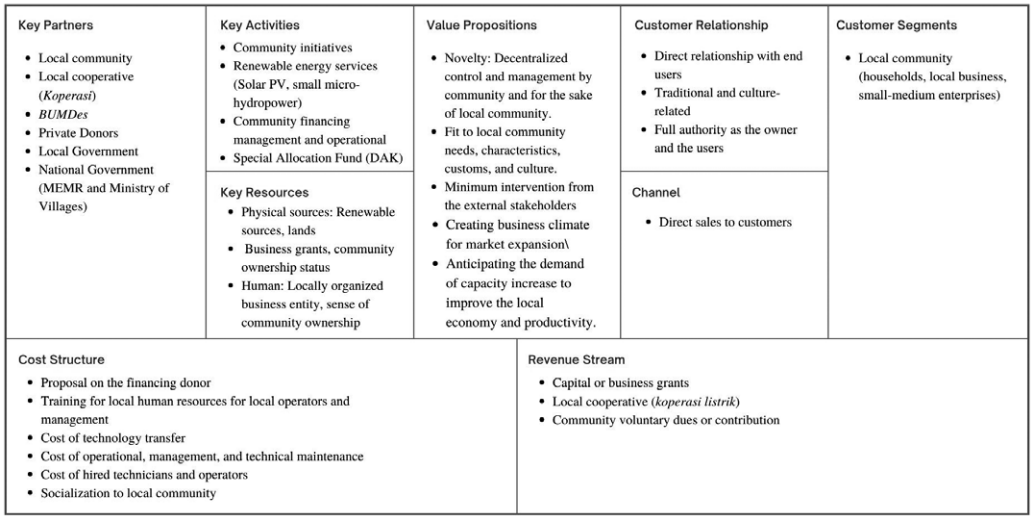


Figure 4. Business Model Canvas on Community-fully Owned Energy Project *(Analyzed by the authors)*

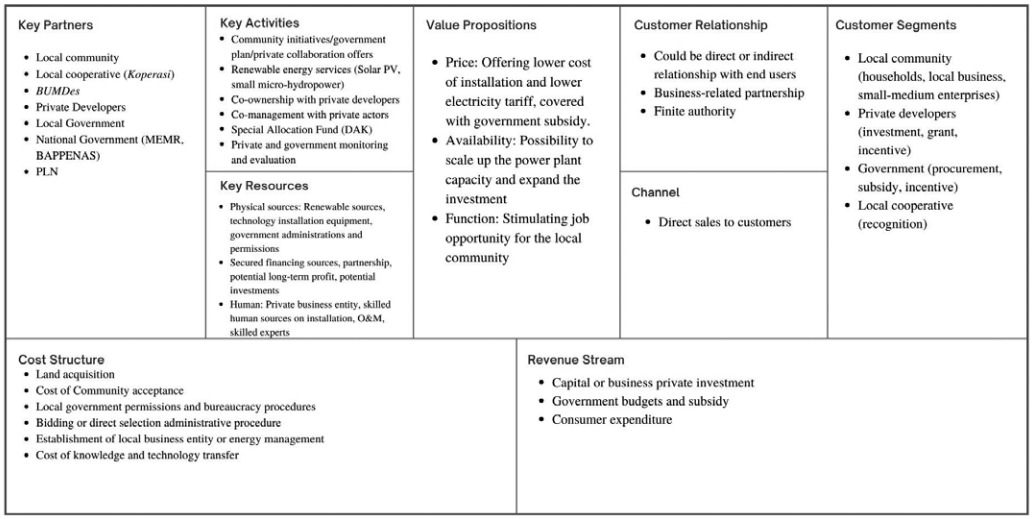


Figure 5. Business Model Canvas on Co-ownership energy business model *(Analyzed by the authors)*

4.2 Barriers of Implementation

The existing barriers within the localized community energy project vary depending upon the implemented business models and the scale of the installed power plant. First, in the context of community-owned energy project, the local cooperatives as the locally-controlled business entity found that the lack of financial security is the primary identified barrier during the implementation process. Although the community-owned energy project receives the funding from external private donor company or organization, the allotment of funding is used for technology equipment and installation of the power plant, such as generator procurement, solar PV array, battery bank installment, and the electric grid supply.

According to the stakeholders' interviews, international private organizations, such as JICA and HIVOS mostly contribute to the community project financing and have less intervention and involvement within the management. Since the principal goal of establishing community-owned energy project is to provide electricity supply to rural local community, business activities and profits are considered as the least priority. According to the literature reviews, most of previous studies show that community-owned energy project primarily focuses on fulfilling the needs of local community in terms of electricity demand for lightning and other household activities. On one hand, the revenue streams are limited to the voluntary contribution of community. On the other hand, the electricity tariff in community fully-owned energy project is decided based on the agreement of local community and cooperatives which makes this business model is not feasible to receive governmental subsidy for the electricity tariff. This kind of system tends to be vulnerable in the context of project and finance sustainability for the long-term. Paticularly, in the case of solar PV technology that requires high-cost maintenance and repair in the emergency case, community-owned project faces difficulties in this term.

Secondly, with respect to the co-owned energy projects, they incline to be less susceptible in the context of financial security. If community is in partnership with the government, MEMR has designated a specific area and budget project for renewable energy development within the co-owned energy. The sources of the project budget also come from potential various stakeholders, which could be private donors, international grant donors, including national budget (*APBN*) that has been regulated within the national energy plan of Indonesia. In this case, the pricing system is decided following the flooring electricity tariff determined by PLN. Therefore, within the co-owned energy company, the consumers feasibly receive the governmental subsidy for the electricity tariff reduction, in particular among underprivileged citizens in rural and remote areas. However, in the sense of energy project procedurals, this type of the localized community energy business models has reliability on governmental bureaucracy procedures, as the project area is legally categorized under governments or private's business areas. Meanwhile, in the community-fully owned energy, community has lack business on governmental bureaucracy, since the business area is not connected to the national grid and legal authority's business area. Local cooperatives, as the main actor of management of community-owned energy project, for instance, are not required to propose the repair check and maintenance if there are technical and managerial troubles related to power plants, including the local control at the household levels. In this case, the dependency of community on authorities' power is less than compared to co-ownership model. Most stakeholders during the interviews agreed that the matter of cost is the primary barriers in terms of operational, management and maintenance under the community-owned energy scheme. This matter becomes the potential hindrance for the sustainability of the community-owned energy project.

4.3 Potential Opportunities

Despite of the remaining barriers and drawbacks among those two different localized community-based energy schemes, each of them has potential opportunities. According to the above-mentioned literature studies, most of them highlighted that through community-owned energy project, the local citizens and organizations are provided with more spaces of learning and empowered. The system within the community-

owned energy project can bring energy independency and energy security closer to the community, not merely because of the electricity grid position, but also the control and management is operationalized locally at the household and/or local cooperative's controls. Through community-owned energy scheme, community can gain more socio-economic benefits. Local cooperatives, in particular, can conduct the community services and at the same time generate the direct economic benefits and intangible advantages to the local community, such as knowledge, technical and managerial skills, including the access to control the demand, supply, and the community expectation management towards the transitions in decentralized system. These potential opportunities might not have within the co-owned energy scheme, as the control and managerial tend to be centralized by powerful actors, for instance private developers and governments. The top-down managerial scheme might hinder the knowledge generations to the local community. The interdependencies and interconnections between community and private developers and government incline to be significant and complex. However, this scheme could provide communities to the access of modernization and acceleration of technology development in their areas. The co-owned energy scheme can bring open access to the energy investment to increase the local economic productivity.

5. Conclusion

In the community-based energy project, community participation depends on agreement and contract to which the involved actor's community agree. Therefore, the implementation of ownership scheme in community energy can be varied in terms of arrangements, structures, and level of inclusivity. In addition, willingness of community to participate is also connected with the extent to which participation level is opened and accessible for community. Through the localized community energy scheme, community participation is expected to be executed in a concrete form and inclusive program, not merely limited to social participation, also financial inclusion. It is expected to increase community participation in rural energy development and encourage provision of community benefits. Through this way, local community potentially can get more exposures and influence on potential impacts and opportunities. As GoI has enacted supporting policy instruments and regulation frameworks regarding the transparency and open access for local community to the rural energy transition, it is necessary for the local government to minimize the policy implementation gaps of rural energy community scheme. Therefore, community energy, either the community-owned or public private partnership scheme, can increase and maintain the energy supply to rural and remote community. At the same time, it generates tangible and intangible benefits that are in line with the energy technology modernization and local community's needs and expectations. Despite the major role of the local cooperatives in community energy, government existence is necessary to aim tailoring the benefits and potential opportunities from the energy transition implementation. Private sectors also are required to follow the existing local customs and regulations, make the transition process equity, transparent and inclusive, and pull out a mere business interest from the community energy scheme. The implementation of any scheme of community can be optimized if the local business entity or cooperative can be empowered and positioned as the literal main actor of the energy transition process.

Initially, the determination of specific business model or scheme of community energy project in Indonesia basically depends on an area and its characteristics, the potential scale of energy project, and the agreement among the stakeholders. Therefore, there is no one-size-fits-all solution in the context of the determination of business scheme implemented in energy project. In addition, in terms of the implementation of the localized energy project in rural areas of Indonesia, the technology development should be aligned with the local economy and human resources empowerment, including woman and youth participation access provision. Not merely focusing on bringing the electricity to the community, but also thinking on how to improve the quality of human resources are essential. In this way, the community-based energy scheme can run sustainably for the long term and minimize the termination of the energy projects in a short time.

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選択型実験によるプリンタの環境属性に対する消費者選好の分析

加藤修一[*]・中野牧子[**]・柘植隆宏[***]

要旨

環境ラベルをはじめとしたプリンタの環境属性に対する消費者の認識を把握することを目的として、家庭用のモノクロレーザプリンタを購入する状況を想定した選択型実験を実施した。潜在クラスモデルを用いた分析の結果、回答者の中に選好の異なる3つのグループが存在すること、消費電力が少ないことはいずれのグループでも望ましいと評価されること、自身には直接的な利益が生じないバイオマスプラスチックの使用や環境ラベルに対しても一定数の消費者が支払意思額を持つことなどが明らかとなった。

キーワード：消費者選好、選択型実験、プリンタ、環境属性

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Analysis of consumer preferences for environmental attributes of printers using a choice experiment

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Abstract

A choice experiment was conducted to understand consumers' preferences of environmental labels and other environmental attributes of printers, assuming a situation in which they purchase a monochrome laser printer for home use. The results of the latent class model analysis revealed that there were three groups of respondents with different preferences, that low power consumption was positively evaluated in all the three groups, and that a certain number of consumers are willing to pay for the use of biomass plastics and environmental labels that do not directly benefit them.

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選択型実験によるプリンタの環境属性に対する消費者選好の分析

1．はじめに

経済産業省・資源エネルギー庁（2022）によると、2020年度には新型コロナウイルス感染症の拡大による経済活動の落ち込みにより最終エネルギー消費は減少したものの、長期的なトレンドで見ると、産業部門のエネルギー消費が1973年度比で2020年度は0.8倍であるのに対し、家庭部門は1.9倍となっている。持続可能な社会を実現するためには、家庭部門のエネルギー消費の削減が重要である。

家庭部門のエネルギー消費を削減するためには、省エネルギー（以下、省エネ）対応などの環境配慮型の家電製品の市場シェアを高めることが有効であると考えられる。しかし、消費者の製品選択において、環境属性は必ずしも重視されているとはいえない。例えば、加藤他（2021）がプリンタの環境属性の消費者にとっての重要度を、ベスト・ワースト・スケーリング（best-worst scaling：BWS）を用いて調査した結果、プリンタの機能属性（機能・性能に関する属性）と比較して、環境属性（環境問題に関する属性）の重要度は低いことが明らかとなった。また、両面印刷や消費電力といった消費者にとってわかりやすい環境属性の重要度が高い一方、バイオマスプラスチックの使用や環境ラベルの付与といった消費者にとってわかりにくい環境属性の重要度は低いことも明らかとなった。

環境ラベルは、消費者に製品の環境配慮を伝えるための重要な手段である。現在、多くの製造業者は国内のグリーン購入法や欧米の市場に対応するため、各種環境ラベルの取得要件を満足した製品を製造販売している。例えば、日本におけるタイプI環境ラベルであるエコマークの取得状況に関しては、公益財団法人日本環境協会エコマーク事務局のサイトで見ることができる[1]。環境ラベルの取得要件は厳しくなる傾向がある。例えば、エコマーク事務局（2022）によると、複写機・プリンタなどの画像機器に関しては、ドイツのブルーエンジェルの改定にあわせて直近では2022年1月に認定基準が改定されている。こうしたことから、ラベルの取得条件を満たすための環境技術開発への投資のコストは増加する傾向にあると推測される。これに対して、消費者は環境ラベルをどのように認識しているのだろうか。環境ラベル取得のコストが増加する一方で、消費者は環境ラベルの内容や効果を十分に理解しておらず、その付加価値を認めないのであれば、製造業者にとっては環境ラベルの取得にコストをかけ続けることが難しくなる可能性がある。 そのような状態では、環境配慮型の家電製品の需要の増加や、製造業者の環境への取り組みの促進は見込めない。より多くの消費者に環境配慮型の家電製品を購入してもらうためには、どの製品が環境配慮型であるかを消費者が容易に区別できなければならない。環境ラベルはそのための重要なツールであるが、現状では十分に機能していない可能性がある。

そこで本研究では、環境ラベルをはじめとした環境配慮型の家電製品の環境属性に対する支払意思額（Willingness to pay：WTP）を、表明選好法の一種である選択型実験を用いて明らかにする

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ことを試みる。選択型実験はLouviere and Woodworth（1983）によって開発された手法である。選択型実験では、複数の属性から構成される選択肢をアンケートの回答者に提示し、最も望ましいと思うものを選んでもらうことで、選択肢を構成する各属性の重要性を明らかにする。製品の属性に対する消費者の評価を把握するためにも用いられており、近年では家電製品の属性評価にも用いられている。環境配慮型の家電製品の環境属性に対するWTPを明らかにすることで、消費者の環境属性に対する認識を把握することが可能となる。このような情報は、製造業者の環境技術開発への投資の意思決定や、環境活動の指針に利用できる可能性がある。また、環境ラベルのさらなる普及を目指すうえでの有益な検討材料ともなりうると考えられる。

選択型実験を用いて家電製品を対象に環境ラベルに関するWTPを求めた研究は多数存在する。例えばKuhn et al.（2022）は、エアコンを対象としてエネルギー効率性を表すラベルに関する選択型実験を実施し、環境意識・知識がより高い人ほどエネルギー効率性が重要であると評価していることを明らかにしている。Jacobs and Hörisch（2022）は、洗濯機を対象に、製品の耐用年数に関するラベルがエネルギー消費量やブランドよりも重視されていることを選択型実験により明らかにした。 Jain et al.（2018a）は、エアコンのエネルギー効率を星の数で示したラベルに対するWTPを求め、ラベルがプラスに評価されていることを示している。Jain et al.（2018b）は、エアコンと冷蔵庫に関して、星の数で示したラベルに対するWTPを比較し、事前にラベルに関する知識を有している人は、エアコンと冷蔵庫の両者において、よりラベルを評価していることを明らかにしている。Shen and Saijo（2009）は、上海でエアコンと冷蔵庫のエコラベルに対するWTPを調査した。

本研究では、環境配慮型の家電製品としてプリンタを選定した。その理由として、プリンタは家電製品の中でも環境への取り組みが積極的な製品の1つであることが挙げられる。日本バイオマスプラスチック協会のバイオマスプラ（BP）マーク製品取得リストには、506の製品の中に23のプリンタ関連の製品が含まれている（日本バイオマスプラスチック協会，2020）。また、別の理由として、選択型実験の実施にあたり、アンケート調査が必要となることが挙げられる。アンケート調査では多くの場合、回答者に提示できる情報量に制限がある。例えば、家電製品であればデザイン性が消費者の購入意欲に結び付くことがしばしばある。しかしながら、アンケート調査ではデザイン性について十分に回答者に情報提供することが難しい。その点、プリンタは家電製品であると同時に事務機器でもあるため、デザイン性の影響は他の家電製品に比べ小さく、カタログに表示された機能や性能だけで購入することが可能であると考えられる。したがって、アンケート調査に適した家電製品としてプリンタを選定した。

加藤他（2021）で述べられている通り、プリンタの環境技術には、前述したバイオマスプラスチックのトナーおよび筐体への利用以外にも、省エネ技術や両面印刷がある。省エネの技術開発に関しては、電子写真技術（レーザプリンタ）、インクジェット技術ともに製造業者は積極的に実施しているが、特に電子写真技術で活発である。電子写真技術はトナーの定着工程での消費電力が高く、定着技術の更なる省エネ化とFPOT（First print out time）の両立が期待される。また、両面印刷は古くからある環境技術の1つであり、現在はプリンタにエコマークを付与する要件の1つとなっている。

これら環境技術が一定の要件を満足した結果、環境ラベルが多くのプリンタに付与されている。環境ラベルはISOにより3つに分類される。第1はタイプⅠ環境ラベル（一例として、エコ

マーク）である。タイプⅠ環境ラベルの合否判定は第三者機関により実施されている。第2は、各事業者が合否判定を実施するタイプⅡ環境ラベルである。第3は、エコリーフに代表されるタイプⅢ環境ラベルである。タイプⅢ環境ラベルは製品のライフサイクルにおける環境負荷を定量化したもので、検証は実施されるが合否判定は実施されない。

このように、プリンタには複数の環境属性が存在する。加藤他（2021）は、環境属性を含むプリンタの各属性の重要度をBWSを用いて調べているが、WTPは明らかにしていない。環境属性に対するWTPの情報は、環境配慮型製品の研究開発を進める事業者にとっても有益であると考えられる。しかし、筆者らの知る限りプリンタを対象として、環境ラベルをはじめとした環境属性に対するWTPを求めた研究は存在しない。そこで本研究では、プリンタの複数の環境属性に対するWTPを選択型実験を用いて明らかにする。

2．選択型実験

選択型実験を実施するにあたり設定した属性とその水準は以下の通りである。なお、プリンタは家庭用のモノクロレーザプリンタを仮定した。

まず、プリンタの機能属性と環境属性をあわせ持つ属性として「自動両面印刷機能」と「消費電力」を使用した。自動両面印刷機能については、「あり」、「なし」の2水準を設定した。消費電力については「400ワット」を標準的な消費電力と想定し、それよりも少ない「200ワット」と、それよりも多い「600ワット」の計3水準を設定した。

次に、環境属性として「バイオマスプラスチックの使用」と「環境ラベルの付与」を使用した。バイオマスプラスチックの使用については、「あり」、「なし」の2水準を設定した。環境ラベルの付与については、3つの種類を表す「タイプⅠ」、「タイプⅡ」、「タイプⅢ」と、ラベルが付与されていないことを表す「なし」の計4水準を設定した。

これらに、製品の価格を表す「価格」を加えた計5属性とした。価格は製品の選択において重要であるとともに、選択型実験によってWTPを推定するために必要となる属性である。価格の水準は「1万円」、「3万円」、「5万円」の3水準を設定した。

このように設定した各属性の水準を直交配列にしたがって組み合わせることで、選択型実験の質問に用いる選択肢を作成した。そして、作成された選択肢の中から選ばれた2つの選択肢と、いずれも望ましくないと考える場合に選択可能な「いずれも購入しない」の計3つの選択肢を回答者に提示した。表1は本研究で実施した選択型実験の質問例である。製品Aは自動両面印刷の機能が付いていて、消費電力が標準の400ワットであり、バイオマスプラスチックが使用されていて、タイプⅠ環境ラベルが付いている、価格が5万円のプリンタを表している。製品Bは異なる特徴を持つプリンタを表している。なお、ここで属性として取り上げられた以外の特徴は、いずれの製品でも同様であると仮定されている。回答者は、製品Aと製品Bを比較して、望ましいと思う方を選択する。また、いずれも望ましくないと思う場合は、3つ目の選択肢である「いずれも購入しない」を選択することができる。1人の回答者に、内容の異なる質問を8回行った。このような仮想的な製品選択行動のデータを統計的に分析することで、回答者の各属性に対する評価を明らかにする。なお、回答者が属性の内容を理解したうえで選択型実験の質問に回答できるよう、選択型実験の質問の前に表2に示すような各属性の説明を提示した。

表1　選択型実験の質問例

	製品A	製品B	
自動両面印刷機能	あり	なし	いずれも購入しない
消費電力	標準400ワット	200ワット	
バイオマスプラスチックの使用	あり	あり	
環境ラベルの付与	タイプⅠ	なし	
価格	5万円	3万円	
回答欄			

表2　回答者に提示した属性の説明

属性	説明
価格	製品の販売価格のこと。
自動両面印刷機能	印刷時にパソコンの操作画面から、両面印刷か片面印刷を選べる機能です。 両面印刷を選ぶと、用紙の両面に自動で印刷ができるため、簡単に用紙の節約ができます。
消費電力	印刷中にプリンターが消費する電力で、単位はワットです。 標準的なモノクロレーザープリンターの場合、消費電力はおよそ400ワットです。 消費電力が200ワット増えるごとに、10枚あたりの電気料金はおよそ0.06円高くなり、CO2（二酸化炭素）排出量はおよそ2.2g増えます。
環境ラベルの付与	環境ラベリング制度とは、環境負荷の低減に役立つ商品や情報開示に、環境ラベルを添付する制度のことです。プリンターに付与される環境ラベルは、認定機関、認定基準により、下記表の3つに分類されます。

	タイプⅠ	タイプⅡ	タイプⅢ
審査機関	第三者機関	各事業者	検証員資格を有する検証員 ※検証員の所属は、第三者機関でも、各事業者でも、どちらも可。 検証員の認定は第三者機関が行います
審査内容	環境配慮の基準を満たしているか	環境配慮の基準を満たしているか	第三者機関の定めた項目を、定めた方法で適正に公開しているか
環境配慮への合否判定	あり	あり	なし
例	画像 エコマーク	画像 例　某企業名	画像 〈ライフサイクルにおける主な環境負荷〉 ○エネルギー消費量　**MJ ○温暖化負荷（CO2換算）　**kg ○酸性化負荷（SO2換算）　**kg ○鉱物資源負荷（鉄鉱石換算）　**kg ○エネルギー資源負荷（原油換算）　**kg （**は数値例が入る） 例　エコリーフとその内容の一部

※ここでのライフサイクルとは、資源採取から製造、物流、使用、廃棄・リサイクルまでの製品の全過程を含んでいます。

バイオマスプラスチックの使用	地上にある植物（主にトウモロコシやサトウキビ）を原料としたプラスチックが、製品に使用されているかどうか。 プリンターのプラスチック部品の重量は1台当たりおよそ4kgであり、使用する場合はその内およそ1kgをバイオマスプラスチックにします。 全てを石油由来のプラスチックにした場合に比べ、プリンターの焼却時に1台あたり1kgのCO2（二酸化炭素）の削減が見込めます。 ※バイオマスプラスチックの使用の有無は、環境ラベルの付与の条件には含まれません。

注）上記の説明は、アンケート実施当時の状況に基づく。

選択型実験では、回答者の効用関数に以下のランダム効用モデルを仮定する。

$$U_{ni} = V_{ni} + \varepsilon_{ni} \quad (1)$$

ここで、U_{ni}は回答者nが選択肢iから得る効用であり、確定項V_{ni}と誤差項ε_{ni}の和で表されるとする。線形の関数形を仮定すると、本研究においてV_{ni}は式 (2)のように表される。

$$\begin{aligned} \mathrm{V_{ni}} = \beta_1 Duple_{ni} + \beta_2 E200_{ni} + \beta_3 E400_{ni} + \beta_4 Bio_{ni} \\ +\beta_5 Type1_{ni} + \beta_6 Type2_{ni} + \beta_7 Type3_{ni} + \beta_8 Price_{ni} + ASC_i \end{aligned} \quad (2)$$

ここで、$Duple_{ni}$、$E200_{ni}$、$E400_{ni}$、Bio_{ni}、$Type1_{ni}$、$Type2_{ni}$、$Type3_{ni}$、$Price_{ni}$は、それぞれ自動両面印刷機能あり、消費電力200W、消費電力400W、バイオマスプラスチック使用、タイプⅠ環境ラベルあり、タイプⅡ環境ラベルあり、タイプⅢ環境ラベルありを表す（消費電力については600W、環境ラベルについては付与なしを基準として推定から外す場合）。また、それぞれのβは各変数の係数を表し、ASC_iは選択肢iに固有の定数項（選択肢固有定数）を表す。

回答者は最も高い効用が得られる選択肢を選択すると仮定すると、回答者nが選択肢の集合$C = \{1, 2, \cdots, J\}$の中から選択肢iを選択する確率P_{ni}は、選択肢iから得る効用U_{ni}が、他のいずれの選択肢$j(j \neq i)$から得る効用U_{nj}よりも大きい確率と等しくなる。

$$\begin{aligned} P_{ni} &= \Pr\left(U_{ni} > U_{nj} \quad \forall j \in C, j \neq i\right) \\ &= \Pr\left(V_{ni} - V_{nj} > \varepsilon_{nj} - \varepsilon_{ni} \quad \forall j \in C, j \neq i\right) \end{aligned} \quad (3)$$

ここで、誤差項が独立で同一の第一種極値分布（ガンベル分布）にしたがうと仮定すると、回答者nが選択肢iを選択する確率P_{ni}は、以下の条件付きロジットモデルで表される（McFadden, 1973）。

$$P_{ni} = \frac{\exp(\mu V_{ni})}{\sum_{j \in C} \exp(\mu V_{nj})} \quad (4)$$

係数は最尤法により推定される。なお、μはスケールパラメタであり、1に基準化される。

推定された係数を用いて、各属性に対するWTPを算出することができる。式（2）のような線形の確定項V_{ni}を仮定した場合には、各属性に対するWTPは、各属性の係数を価格の係数で割ったものに-1をかけることで求められる。例えば、自動両面印刷機能に対するWTP（WTP_{Duplex}）は、以下のように求められる。

$$WTP_{Duplex} = -\frac{\beta_1}{\beta_8} \quad (5)$$

この条件付きロジットモデルでは、すべての回答者が同質の選好を持つことが仮定されている。近年は、この仮定を緩和したより一般的なモデルを用いた研究が増えている。そのような

モデルのうち代表的なものが、潜在クラスモデルである（McFadden, 1986, 2001; Swait, 1994; Boxall and Adamowicz, 2002）。これは、回答者の中に選好が異なる複数のグループが存在することを仮定し、それぞれのグループの効用関数のパラメタを推定する方法である。また、それぞれのグループに所属する確率を回答者の個人属性等で説明するメンバーシップ関数を推定することで、選好の多様性が生じる要因を明らかにできる。

回答者nがクラス$s = \{1,2,\cdots,S\}$に属し、選択肢iを選択する確率$Pr_{ns}(i)$は、以下のように表される。

$$Pr_{ns}(i) = \sum_{s=1}^{S}\left[\frac{exp(\zeta \boldsymbol{\gamma_s}' \boldsymbol{z_n})}{\sum_{s^*=1}^{S} exp(\zeta \boldsymbol{\gamma_{s^*}}' \boldsymbol{z_n})}\right]\left[\frac{exp(\mu_s \boldsymbol{\beta_s}' \boldsymbol{x_{ni}})}{\sum_{j\in C} exp(\mu_s \boldsymbol{\beta_s}' \boldsymbol{x_{nj}})}\right] \quad (6)$$

右辺の最初のロジットモデルの式は、個人nがクラスsに所属する確率を表すメンバーシップ関数であり、続くロジットモデルの式は、クラスsに属する個人nが選択肢iを選択する確率を表す。ここで、z_nは個人属性等のベクトル、γ_sは推定される係数のベクトル、ζはメンバーシップ関数のスケールパラメタ、x_{ni}とx_{nj}は選択肢iとjの属性のベクトル、β_sはクラスsに固有の係数のベクトル、μ_sはクラスsに固有のスケールパラメタを表す。係数は最尤法により推定される。

3. 結果と考察

本研究では、調査会社の登録モニターを対象にインターネットによるアンケート調査を実施した。アンケートの実施期間は2014年の2月から3月で、対象は国内の20歳から69歳までの男女である。その結果、633人から回答を得た。回答者の個人属性は表3の通りである。

表3　回答者の個人属性

個人属性	人数
性別	男性：312人、女性321人
年齢	20代：108人、30代：141人、40代：116人、50代：113人、60代：155人

5064の選択型実験のデータ（633人×8回）を分析に用いた。回答者の選好が均一でない可能性を考慮して、選好の多様性を把握することが可能な潜在クラスモデルによる推定を行った。変数として、価格については数値を使用し、その他についてはダミー変数を使用した。関数形やクラス数を変えて複数の推定を行ったが、ここでは、解釈が容易な3クラスモデルの結果を報告する[2]。推定結果は表4の通りである。

2　クラス数の決定に当たっては、情報量基準に基づく検討も行った。1クラスモデルのAICは8850.4、BICは8909.1、2クラスモデルのAICは6702.9、BICは6820.5、3クラスモデルのAICは6434.2、BICは6610.5、4クラスモデルのAICは6340、BICは6575.1であった。潜在クラスモデルのクラス数は情報量基準や解釈のしやすさに基づき総合的に判断されるべきである（Scarpa and Thiene, 2005; Hynes et al., 2008）。したがって、AICやBICに基づく比較では4クラスが選ばれるが、本研究では解釈の容易さを重視して3クラスモデルを採用した。

メンバーシップ関数に年齢、性別などの個人属性の変数を含めた推定も行ったが、それらは有意にならなかったため、メンバーシップ関数は推定しなかった。各クラスのシェアは、クラス1が46.6%、クラス2が19.2%、クラス3が34.2%と推定された。

効用関数の推定結果は以下の通りである。なお、ASC3は、選択肢3の選択肢固有定数を表す。クラス1では、価格はマイナスに有意となった。これは、価格が上昇すると、プリンタの購入による効用が減少し、選択確率が低くなることを意味する。

また、プリンタの機能属性と環境属性をあわせ持つ自動両面印刷機能は、有意にならなかった。これは、自動両面印刷機能の有無は効用に影響を与えず、選択確率に影響しないことを意味する。同じく機能属性と環境属性を併せ持つ消費電力は、600Wを基準とした場合、400W、200Wともにプラスに有意となった。400Wよりも200Wの方が係数が大きいことから、消費電力が小さくなるほど効用が増加し、選択確率が高まることが明らかとなった。

プリンタの環境属性であるバイオマスプラスチックの使用は、有意にならなかった。これは、バイオマスプラスチックの使用は効用に影響を与えず、選択確率にも影響しないことを意味する。

環境ラベルについては、タイプⅠ、タイプⅡ、タイプⅢともに有意にプラスとなった。これらの環境ラベルは効用にプラスの影響を与え、選択確率を高めることを意味する。3種類の中では、タイプⅠの係数が最も大きく、次にタイプⅢ、最後がタイプⅡとなった。このことから、3種類の環境ラベルの中ではタイプⅠが最も高く評価されることが明らかとなった。

クラス2でも、価格はマイナスに有意となった。また、消費電力については、200Wのみプラスに有意となった。400Wは有意でないことから、400Wは600Wと同程度に評価されているが、200Wは600Wより望ましいと評価されていることがわかる。

自動両面印刷機能については、クラス1と異なり、プラスに有意となった。ここから、クラス2では、自動両面印刷機能が搭載されると、効用が増加し、選択確率が高まることがわかる。バイオマスプラスチックの使用も、プラスに有意となった。ここから、クラス2ではバイオマスプラスチックの使用が望ましいと評価されていることがわかる。このように、バイオマスプラスチックの使用についても、クラス1と異なる結果が得られた。

環境ラベルについては、タイプⅠとタイプⅢは有意にならなかった。一方、タイプⅡはマイナスに有意となった。ここから、タイプⅠとタイプⅢの環境ラベルは効用に影響を与えず、選択確率にも影響しないが、タイプⅡの環境ラベルは選択確率を低下させることがわかった。

クラス3では、クラス1やクラス2と同様に価格はマイナスに有意となった。また、消費電力は200W、400Wともにプラスに有意となり、係数は400Wよりも200Wの方が大きくなった。バイオマスプラスチックはプラスに有意となった。一方で、自動両面印刷機能と環境ラベルについては、いずれも有意に推定されなかった。

推定された効用関数の係数をもとに算出されたプリンタの各属性に対するWTPを表4の各クラスの最右列に示す。これらは、それぞれの特徴を持つプリンタを購入するために、そうでないプリンタを購入する場合と比較して、消費者が追加的に支払ってもいいと考える金額を意味する。したがって、これらの結果は、企業の製品開発や環境面での取り組みに関する検討において有益であると考えられる。環境属性であるバイオマスプラスチックの使用や環境ラベルに対しても、一定数の消費者がWTPを持つことは注目に値する。ここから、消費者の製品選択において、

環境属性が無視できない影響を持つことがわかる。

400Wと200Wに対する評価の程度は異なるものの、消費電力については、いずれのクラスでも小さいほど望ましいと評価されることが明らかとなった。消費電力が少ないと、環境負荷が少なくなるだけでなく、電気代も少なくなるため、消費者自身にも利益が生じる。このことから、多くの消費者が消費電力が少ないほど望ましいと評価したものと考えられる。

また、環境ラベルに関しては、クラス1はタイプⅠ、Ⅱ、Ⅲのすべてを望ましいと評価しており、中でもタイプⅠを最も望ましいと評価している。タイプⅠは第三者の審査に合格した製品のみに付与されるものであり、環境に配慮していることを表すものである。第三者が審査することによる信頼性や、一目で環境負荷が少ないことが理解できるわかりやすさが評価されたものと推測される。クラス2ではタイプⅠとタイプⅢは効用に影響せず、タイプⅡは効用にマイナスの影響を与えている。明確な理由は明らかでないが、タイプⅡは第三者機関が関与しないため、グリーンウォッシュを懸念している可能性が考えられる。クラス3では、環境ラベルはタイプⅠ、Ⅱ、Ⅲのいずれも効用に影響しない。以上より、環境ラベルに関心のある消費者とそうでない消費者が存在しており、タイプⅡラベルについてはマイナスに評価する消費者もいることが明らかとなった。

表4　潜在クラスモデルの推定結果

	クラス1（46.6%）			クラス2（19.2%）			クラス3（34.2%）		
変数	係数 （標準誤差）		WTP （円）	係数 （標準誤差）		WTP （円）	係数 （標準誤差）		WTP （円）
両面印刷	1.10632 (0.80207)		—	2.76942 (0.32332)	***	30627.1	-0.23342 (0.16951)		—
200W	3.11160 (1.59330)	*	23812.8	1.47744 (0.37061)	***	16339.0	2.28956 (0.29688)	***	19655.7
400W	0.81379 (0.15907)	***	6227.9	0.16114 (0.20257)		—	1.57091 (0.30084)	***	13486.2
バイオマス プラスチック	-0.08148 (0.14506)		—	0.91107 (0.18155)	***	10075.5	0.28340 (0.15742)	*	2433.0
タイプⅠ	1.49763 (0.85533)	*	11461.3	-0.36135 (0.33151)		—	0.03173 (0.22277)		—
タイプⅡ	0.99865 (0.25389)	***	7642.6	-0.59244 (0.22242)	***	-6551.8	0.25742 (0.18172)		—
タイプⅢ	1.44031 (0.82313)	*	11022.6	0.14604 (0.22493)		—	-0.09930 (0.20645)		—
価格（万円）	-1.30669 (0.09440)	***	—	-0.90424 (0.10713)	***	—	-1.16483 (0.07062)	***	—
ASC3	-5.93611 (0.90586)	***	-45428.6	-1.17608 (0.32650)	***	-13006.3	0.41485 (0.30726)		—
観測値の数	5064								
対数尤度	-3190.11556								
マクファーデンの 疑似決定係数	0.42659								

注）*、***は、それぞれ10%、1%水準で有意であることを示す。

4. おわりに

本研究では、環境ラベルをはじめとしたプリンタの環境属性に対する消費者の認識を把握することを目的として、家庭用のモノクロレーザプリンタを購入する状況を想定した選択型実験を実施した。潜在クラスモデルを用いた分析の結果、以下のことが明らかとなった。

第一に、回答者の中に選好の異なる3つのグループが存在することが確認された。回答者の5割弱がクラス1に、2割程度がクラス2に、3割強がクラス3に所属している。

第二に、環境ラベルに対する評価はクラス間で大きく異なることが明らかとなった。クラス1はいずれのタイプの環境ラベルもプラスに評価しているのに対して、他の2つのクラスでは、タイプⅠ、タイプⅢともに評価されていない。タイプⅡはクラス3では評価されておらず、クラス2ではマイナスに評価されている。

第三に、自動両面印刷機能とバイオマスプラスチックについても、クラス間で評価が異なることが明らかとなった。自動両面印刷機能はクラス2でのみプラスに評価されており、バイオマスプラスチックはクラス2とクラス3でプラスに評価されていることが明らかとなった。

第四に、他の属性と異なり、消費電力が少ないこと、特に200Wであることは、いずれのクラスでも望ましいと評価されることが明らかとなった。

第五に、環境属性であるバイオマスプラスチックの使用や環境ラベルに対しても、一定数の消費者がWTPを持つことが明らかとなった。ここから、消費者の製品選択において、環境属性が無視できない影響を持つと考えられる。

このように、本研究によって、プリンタの環境属性に対する消費者の選好を明らかにすることができた。ただし、本研究は比較的少数のサンプルに基づく分析である点に注意が必要である。たとえば、潜在クラスモデルのメンバーシップ関数では個人属性の変数が有意にならなかったが、それには観測値の数の少なさが影響している可能性がある。また、関数形やクラス数を変えて様々な推定を行ったが、中には推定に失敗するものもあった。これも観測値の数の少なさが影響している可能性がある。今後は、より多くのサンプルを使用して、さらに信頼性の高い分析を行うことが重要な課題である。

また、本研究で得られたWTPは、全体的にやや高めであると思われる。選択型実験を含む表明選好法では、支払いの仮想性に起因する仮想バイアスが大きな問題となっている（Loomis, 2011）。本研究で得られたWTPも仮想バイアスの影響を受けている可能性を否定できない。今後は、実際の購買データを用いた顕示選好法による分析や、実際の支払いを伴う経済実験などを行い、仮想バイアスの影響を除外したWTPを推定することが重要な課題である。

さらに、環境ラベルに関しては、特にWTPが高めに算出されている可能性がある。このアンケートでは、選択型実験の質問の前にも、環境ラベルに関する説明や質問を行っている。それにより回答者の環境ラベルに対する関心が高まった状態で選択型実験の質問を行った結果、環境ラベルに対するWTPが高めに算出された可能性が考えられる。環境ラベルに関する説明や質問を行う前に選択型実験の質問を行い、普段の認識に基づくWTPを推定することも、今後の重要な課題であると考えられる。

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上智地球環境学会

1．設立主旨

持続可能な地球社会システムを形成するために、社会科学、人文科学そして自然科学の成果を総合した地球環境学の創成と発展の必要性が今日誰の目にも明らかになってきています。上智地球環境学会は、これに貢献するために研究者の知的コミュニケーションと人的ネットワークの形成およびそれを基礎にした、研究と人材育成のダイナミックな展開を目的として発足しました。自由でオープンな議論、自立的な研究の相互依存、琢磨によって新しい文明創造的な場を広く提供していきます。

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(1) 定例研究会の開催
(2) 研究紀要『地球環境学』の発行
(3) ディスカッションペーパーの発行
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