Snapshot of Indonesia's Provincial Green Economies: A Complexity Approach

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November 2024

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ABSTRACT

Introduction. *This study investigates Indonesia's green complexity at the provincial level, examining the country's capabilities to produce sophisticated environmental goods while pursuing its 2060 net-zero emissions target. The research uniquely contributes by applying Green Complexity Index (GCI) analysis at the subnational level, revealing critical intra-country differences in green development potential.*
Data Collection Methods. *The study analyzes 493 green products identified from IMF, OECD, and WTO data, categorized into renewable energy, pollution management, clean technologies, and resource management. Trade competitiveness data from WITS and BPS covers 34 Indonesian provinces and 226 countries, using 2022 trade data.*
Data Analysis*. The methodology employs Economic Complexity Index (ECI) calculation, Green Complexity Index (GCI) derivation, and Product Distance measurement to assess regional green capabilities and development trajectories.*
Results and Discussion. *DKI Jakarta leads in green product exports (370 products) and competitive exports (48 products), with a weak positive correlation between ECI and GCI across provinces. While Jawa Barat leads in ECI (1.48), Jakarta tops GCI rankings (13.12). Regional disparities show Kepulauan Riau leading in renewable energy (GCI: 3.05) and clean technologies (GCI: 8.34), while Jakarta dominates pollution management (GCI: 4.53).*
Conclusion. *The study reveals substantial regional variations in green complexity across Indonesian provinces, concentrated in developed regions. The findings suggest the need for province-specific strategies, knowledge transfer mechanisms, and innovative green finance solutions to promote sustainable development.*

Keywords: Green Complexity Index, Economic Complexity, Product Distance, Regional Development

A. INTRODUCTION

Over the next three decades, Indonesia ambitiously targets net zero emissions by 2060. With an economic goal of achieving 8 percent GDP growth by 2045, this sets a long path towards the country's environmental targets. Since 2003, Indonesia has remained highly dependent on fossil fuels, with coal and natural gas exports accounting for nearly 20 percent of net goods exports (International Energy Agency (IEA), 2021).

In achieving its ambitious targets, there are five possible sectoral pillars that can each contribute to Indonesia's emission targets (CSIS, 2021), these include: 1) Agriculture, Forestry, Land Use: Net carbon sink from FOLU, implement restoration program and prevent deforestation; sustainable agriculture; 2) Waste: Manage industrial waste; reduce municipal solid waste through law enforcement; domestic wastewater treatment; 3) Energy: Reduce: Increase energy efficiency, Replace: Renewables deployment, Remove: CCS technology; 4) Transport: Revamp urban transportation; increase fuel efficiency; invest in electric future and hydrogen mobility; 5) Green Product Development: Modernize and decarbonize emission-intensive industries and the adoption of green technologies and green processes in supply chain.

Despite Indonesia's ambitious targets and potential ways to achieve them, substantial environmental challenges faced in the country still persist, including deforestation, energy consumption, and unsustainable agricultural practices, indicated by the extractive nature of resources acquisition (Firdaus, 2021; Poverty Action Lab, 2022). Indonesia's reliance on fossil fuels further exacerbated these environmental challenges, which presents a significant hurdle to its transition to renewable energy (FWI, 2023). However, the Indonesian government has begun taking steps to tackle these issues through frameworks such as the Green Growth Program, offering a roadmap for policy planning and investment in green growth initiatives (Bappenas, 2018). Moreover, efforts such as the Low Carbon Development Initiative (LCDI) aim to measure the country's progress towards a sustainable economy, which in turn promotes the adoption of green products at both the national and provincial levels (LCDI, 2022).

Yet, on a strategic level, we identify a gap in the lack of coordinated policy to implement green transition strategies. There are three guiding policies that underpin Indonesia's green transition roadmap. These include Visi Emas 2045, whereby one of the pillars of Visi Indonesia 2045 is "Sustainable Economic Development", which emphasizes the reduction of emissions by 34-41% from the baseline achieved through Low Carbon Development in various sectors, especially the energy sector. Secondly is RPJMN, where three guideposts are mentioned, namely improving environmental quality, improving disaster resilience and climate change, and low-carbon emission development. Lastly, RIPIN also outlines the green industry development through efficient use of natural resources and environmental preservation, where the strategy involves transforming existing industries and building new green ones, supported by certification and government incentives. These planning and regulations lack strategic steps that are applicable to the context of provinces, considering the disparity that exists in terms of environmental challenges and capabilities

In order to develop a strategic and actionable roadmap for Indonesia to transition to greener economies, it requires a framework that addresses 1) What is the capability of Indonesia's economy in developing green products? And 2) What new green products should Indonesia tap into? Globally, economies are making efforts to solve climate change and transition to greener economies, including Indonesia, by shifting production capabilities towards more sophisticated and sustainable green products. This paper seeks to map Indonesia's provincial production capabilities, identifying provinces better positioned to lead in the green transition and those requiring further development, using the Green Complexity Index (GCI).

Efforts to increase green production also face significant energy transition challenges. Transitioning Indonesia's energy mix is one of the key struggles highlighted in recent policy discussions, especially on the supply-side (BRIN, 2021; Zahroh & Najicha, 2022). However, from the demand-side, research shows that the willingness of Indonesian consumers to pay more for sustainable products is increasing, signaling a shift in public perception toward green products (Statista, 2022). Yet, to fully understand these dynamics, it is necessary to assess the regional variations in green product production and consumption.

In developing green products, the tension between economic growth and environmental sustainability emphasizes the importance of integrating the concept of analyzing Indonesia's capability know-how into Indonesia's industrial and policy planning in green transitioning. Green Complexity Index builds upon the concept of economic complexity, which illustrates a country's productive capability to produce sophisticated goods with environmental sustainability, also called green products or environmental products. It evaluates the capabilities of an economy to produce goods and contribute to a low-carbon future while maintaining economic resilience (Mealy & Teytelboym, 2022). Indonesia's ambitious net-zero targets would require the analysis of green complexity, especially at the regional level, to map out its capacity to drive sustainable growth.

Research has shown that economies with higher green complexity are better positioned to develop competitive advantages in green technologies, such as renewable energy, low-carbon innovations, and sustainable products (Caldarola et al., 2024; Napolitano et al., 2022; Sbardella, n.d.). Other studies have mentioned the relevance of green complexity in reducing carbon emissions, whereby there exists a correlation with lower CO2 emissions and improved environmental performance (Tokpunar & DALGIÇ, 2024).

Previous research has explored production capabilities in Indonesian provinces. Studies such as those by Apriyanti et al. (2018) and Damayanti (2016) emphasize that regional disparities in industrial infrastructure and export capabilities directly influence each province's capacity to engage in green production (Apriyanti et al., 2018; Damayanti, 2016). However, in order to grasp a clearer picture of regional capabilities in transitioning to greener economies, it requires a more nuanced tool that represent such idea. Therefore, the Green Complexity Index (GCI) is a valuable tool in mapping out these variations, allowing policymakers to identify which provinces have the highest potential to contribute to Indonesia's green economy by producing sophisticated green products.

Existing indices such as the Green Growth Index published by LCDI and other sources have highlighted the importance of targeted investments and policy interventions at the provincial level to foster green growth (Damayanti, 2016; Green Growth Bappenas, 2018). In addition, collaboration across sectors and stakeholder engagement are also being highlighted in addressing environmental challenges and ensuring a sustainable future for Indonesia's economy (Climate Impacts Tracker, 2022; Poverty Action Lab, 2022). However, this paper aims to build on this foundation by assessing Indonesia's Green Complexity Index across its provinces, highlighting their production capabilities in producing sophisticated green products, and suggesting targeted policy interventions, which is ultimately based on assessing their productive capabilities or know-how.

While the concept of green complexity has been extensively studied at the national level, there is a significant gap in the literature regarding its application at the regional provincial level, particularly in Indonesia. Previous studies, such as Mealy & Teytelboym (2022), have analyzed the Green Complexity Index (GCI) across countries to assess their capabilities in producing sophisticated and environmentally sustainable products. However, these country-level analyses often overlook the heterogeneity and regional disparities that exist within nations such as Indonesia.

Indonesia's diverse economic and environmental landscapes across provinces possesses a unique combination of capabilities, which entails that regional analysis is crucial. The lack of sub-national green complexity analysis means that policymakers lack granular insights into which provinces are more well-positioned to lead in the green transition and which require more support given their endowments. Studies that have examined economic complexity at the regional level (Pérez-Balsalobre et al., 2019; Török et al., 2022) primarily focus on general economic capabilities without explicitly addressing green production. Furthermore, applying GCI at the subnational level has little to no availability, especially in the case of Indonesia. This gap highlights the need for a comprehensive analysis of green complexity within Indonesia's provinces to better understand regional capabilities and inform targeted policy interventions.

In this study, we conduct an empirical analysis by applying Hidalgo and Hausmann's method (Hidalgo & Hausmann, 2009) to determine the economic complexity and green complexity of Indonesia's provinces in the 2022 period, as well as the distance of each province to its nearest products to obtain further information about the nearest most feasible green or environmental products that each province can tap into. Hence, this study aims to explore several questions. First, how diversified is Indonesia's export profile concerning green products, and second, which new green products can Indonesian provinces strategically focus on to enhance their export portfolio. The main hypothesis of this study is that, provinces with higher GDP per capita and more government priorities would have higher economic complexity, and hence higher green complexity as well as they are well-positioned to transition to greener economies.

The significance of this research lies in its bottom-up approach to understanding green economic development at the provincial level through understanding their existing know-how. By analyzing export data and complexity metrics, the study provides a data-driven framework for identifying province-specific opportunities and challenges in green transition. The research contributes to both academic understanding of regional green development and practical policy implementation by offering evidence-based insights for sustainable economic planning. The findings will be particularly valuable for provincial governments in formulating locally-tailored green transition strategies and for national policymakers in allocating resources and support more effectively across regions.

This study makes several key contributions. Firstly, this study pioneers the application of the Green Complexity Index (GCI) at the provincial level within Indonesia, offering a granular view of regional capacities for green transition that has not been previously explored. By focusing on subnational variation, we address the need for localized green growth strategies highlighted in literatures (McKay, 2023; Napolitano et al., 2022). This approach adds a new layer to existing green complexity metrics, traditionally applied at national levels, by revealing critical intra-country differences in green development potential. Secondly, the study provides empirical insights into the significant disparities in green capabilities across Indonesian provinces, supporting the need for policies tailored to local capacities, as advocated by Grillitsch & Hansen (2019) and Y. Zhao et al. (2024). These findings are essential for policy optimization, helping to ensure that green industrial strategies can be effectively matched to regional characteristics, thereby supporting equitable and context-sensitive green development. Thirdly, the methodology developed here is adaptable beyond Indonesia, providing a replicable framework for assessing green complexity at subnational levels in other countries. This contributes a practical tool for policymakers globally to evaluate and optimize green capabilities at a finer scale, addressing the call for localized approaches to complexity-driven green growth (B. Asheim et al., 2017; Stojkoski et al., 2023).

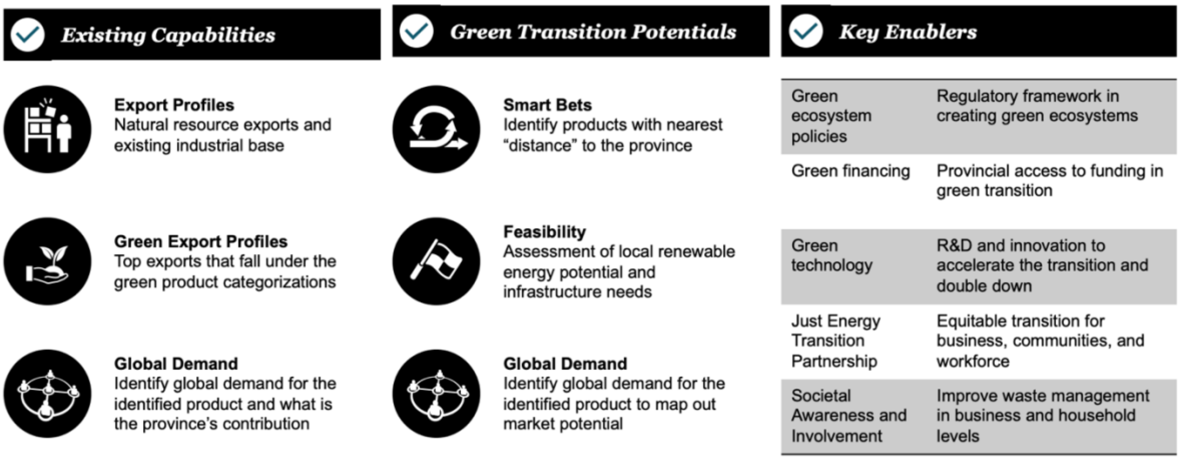

Figure 1. Research Framework

The underlying framework of this research is presented in Figure 1. This study ultimately develops a strategic green production roadmap, which encompasses Indonesia's existing capabilities of producing green products, its green transition potentials, as well as they potential key enablers. Whereby the main data points were involving each province's and country's export capabilities and competitiveness, specifically in green products that are later defined. The study provides insights into the green production capabilities of each province, helping to identify the products where it competitively exports, then looking at its export diversity and product ubiquity. Hence, the product space analysis is conducted, followed by a calculation of their provincial ECI and GCI, thus deriving its existing green product capabilities. Policymakers can use the findings to design targeted interventions that promote green industries or the development of low carbon technologies where they are most viable. By focusing on green complexity, the research supports Indonesia's goals of achieving economic growth while transitioning to a low-carbon economy. Filling the gap in subnational analysis of green complexity adds value to the existing body of knowledge and can inspire a more in-depth exploration of each province's endowments in producing sophisticated green products. Diversifying into green products can enhance the economic resilience of provinces by opening up new markets and reducing dependence on fossil fuels or improving its resource or pollution management.

Our analysis reveals significant regional disparities in green economic development across Indonesian provinces. DKI Jakarta emerges as the leader in green product exports with approximately 370 products and 48 competitive green exports, followed by other major provinces like Jawa Barat and Jawa Timur. The relationship between Economic Complexity Index (ECI) and Green Complexity Index (GCI) shows a weak positive correlation, with Jawa Barat leading in ECI (1.48) while DKI Jakarta tops the GCI rankings (13.12). The analysis of GCI components reveals concentrated capabilities in specific sectors: Kepulauan Riau leads in renewable energy (Renewable Energy GCI: 3.05) and clean technologies (Clean Technologies GCI: 8.34), while Jakarta dominates in pollution management (Pollution Management GCI: 4.53). The generally high product distance values (close to 1) indicate significant challenges in diversifying into new green products for most provinces, though some regions, particularly Jakarta with its lower distance values (0.780 or feasibility of 0.22), show greater potential for green sector diversification. These findings highlight both the achievements and challenges in Indonesia's regional green economic development, suggesting the need for targeted policies that consider local capabilities and development pathways.

B. LITERATURE REVIEW

Green Product and Industry Development

Environmental regulation and innovation normally determine the landscape of green product development, which then serve as fundamental drivers of green industrial transformation, though their effectiveness varies by context. While moderate environmental policy constraints can benefit green development (Zhang et al., 2024), excessive regulations may hinder transformation through increased compliance costs. In terms of the innovation itself, the innovation pathway operates through two distinct channels: green product innovation enables the development of environmentally-friendly products, while green craft innovation enhances production processes (Chen et al., 2023). This dual nature of innovation becomes particularly significant when considering regional variations in development opportunities.

Regions vary considerably in their preconditions and opportunities for green industrial development. Grillitsch & Hansen (2019) develop a comprehensive framework categorizing regions based on their industrial specialization patterns – from those without significant specialization (white regions), to those dominated by polluting industries (brown regions), clean industries (green regions), or a mix of both (multi-colored regions). Each regional type faces distinct challenges and opportunities in pursuing green development. The relationship between resource endowment and green development adds another layer of complexity to this picture. K. Zhao et al. (2021) reveal that resource endowment can either promote or inhibit green development depending on regional context. In areas heavily dependent on resources, a "resource curse" phenomenon may emerge where abundant resources become obstacles to green transformation.

Recent research has increasingly focused on the role of green investment and technological progress in driving industrial transformation. Both R&D expenditures and green finance investments positively impact industrial structure in both short and long run (Chen et al., 2023). Green investment supports development by enabling eco-friendly industrial growth, limiting financing to high-pollution enterprises, accelerating industrial upgrading, and promoting technological innovation. There are three knowledge bases that drive green innovation: analytical knowledge generated through scientific research, synthetic knowledge developed through engineering applications, and symbolic knowledge created through design processes (B. Asheim et al., 2017). The effectiveness of these knowledge bases varies significantly across regional contexts and industrial sectors. Building on this understanding, B. T. Asheim & Isaksen (2002) demonstrate through their study of Norwegian industrial clusters that successful green industry development requires regions to integrate both local "sticky" knowledge embedded in regional contexts and global "ubiquitous" knowledge available internationally. Their research shows how firms strategically combine deep local competencies with international R&D networks to enhance their competitive position in green industries.

This research highlights how the capacity for green industrial development varies considerably across different types of regions. The Indonesian experience documented by Prayogo (2021) provides valuable insights into the practical challenges of implementing green industry development policies. Their analysis reveals that successful transition requires addressing both technical requirements - such as achieving low material and energy intensity - and institutional support mechanisms including climate-tagged budgeting and innovative financing.

Economic Complexity

The Economic Complexity Index (ECI) provides a powerful framework for analyzing economic development through the lens of productive capabilities and collective knowledge. Originally developed by Hidalgo & Hausmann (2009), the ECI ranks countries by the complexity of their goods and the diversity of their exports, based on the idea that productive knowledge is embedded within societies, not individuals. This theoretical framework has since been enhanced by Balland et al. (2022), who further explored how economies progress from simple to sophisticated activities through the building of competitive advantages.

The strong correlation between economic complexity and key development indicators reveals its crucial role in driving sustainable growth. Higher economic complexity levels consistently correspond with increased per capita income and reduced inequality (Hausmann et al., 2014). Economies with complex, diverse industrial bases adapt more effectively to global market changes and technological advancements. Felipe et al. (2012) reinforce these findings through their analysis, showing that countries possessing complex export structures achieve more sustainable economic growth patterns. At the same time, complex economies support innovation and competitiveness, driving long-term growth (Hidalgo & Hausmann, 2009).

Further expanding the ECI framework, recent studies highlight the regional applications of complexity and its implications for sustainability. Ren et al. (2024) introduce a tunable resource allocation model, offering insights into the dynamics of complexity by examining resource distribution within economies, which can be especially useful for tailoring regional complexity strategies. Following that, regional analysis of economic complexity has emerged as a vital tool for understanding local development potential. The Observatory of Economic Complexity (2021) demonstrates the value of examining complexity at subnational levels, which reveals distinct developmental trajectories within countries. For regions with provincial disparities in industrial capabilities, analyzing complexity at a subnational level is essential for understanding local economic dynamics. This approach has proven particularly insightful in studies of Mexican states (de Jesús Gómez & Chávez, 2016) found that regions with higher complexity achieved superior economic outcomes while those with lower complexity struggled with greater inequality. Furthermore, Gao & Zhou (2018) explore China's regional complexity, finding that provinces with high complexity benefit from stronger economic growth and lower income inequality, suggesting that complex, diversified regional economies are more resilient and equitable. Similarly, in Romania and Russia, where higher complexity correlates with economic growth and reduced income inequality, offering lessons for local economic strategies focused on green industries (Liu et al., 2021; Török et al., 2022).

However, resource-dependent economies such as Indonesia face unique challenges and opportunities in building economic complexity. For resource-dependent countries, reducing dependency on primary goods and promoting complexity in higher-value sectors is key to avoiding the "resource curse" (Saad et al., 2023). Similarly, Hausmann et al. (2023) examined Kazakhstan's reliance on oil, illustrating how diversification into complex, sustainable industries like energy and chemicals can build resilience. Bhorat et al. (2019) also emphasize the potential of complexity to drive sustainable growth in African countries, which shows that structural diversification can foster resilience in resource-reliant economies, a strategy particularly relevant for Indonesia's green economic transition.

Further exploring complexity's sustainability implications, Lapatinas et al. (2021) find that countries with higher complexity tend to foster a stronger environmental culture among citizens, suggesting that economic sophistication may drive sustainable behaviors—a valuable insight for Indonesia's provinces aiming to integrate green practices. Lopes et al. (2008) expand the complexity framework by using input-output measures to capture intersectoral dependencies, providing a more nuanced understanding of structural interconnectedness within regional economies, which can inform targeted green industry policies in Indonesia.

Policy implications of economic complexity emphasizes the need for strategic intervention to promote balanced development. Without policies promoting complexity in less-developed regions, inequality can worsen (Balland et al., 2022). This finding also aligns with the European Union's Smart Specialization Strategy, supporting growth by fostering sectors that match regional capabilities and complexity. Ertan Özgüzer & Oğuş-Binatl (2016) explore similar policy implications within the EU, finding that high-complexity regions experience faster economic convergence, a concept that could guide Indonesian policymakers in designing region-specific green development strategies.

The transition toward complex, sustainable economies requires overcoming significant structural challenges. The barriers that economies face in developing complex industries, which often require advanced skills, infrastructure, and institutional support (Alsharif et al., 2018). Hence, investments in human capital and infrastructure can facilitate this shift, supporting economies as they build capacity in high-complexity, green sectors (Felipe et al., 2012). Furthermore, Yildirim (2021) adds that matching productive factors with local capabilities is essential for fostering regional complexity, highlighting a factor-based approach that can guide Indonesia's policy for sustainable regional development. This body of literature solidifies the relevance of economic complexity as both a diagnostic tool and a strategic framework for guiding sustainable, inclusive growth at national and subnational levels. For Indonesia, focusing on complexity at the provincial level offers a pathway to a greener, more resilient economic future, supported by policies that foster local strengths and address structural challenges in each region.

Product Distance and Relatedness

Upon exploring economic complexity, an important concept that underlies the analysis is product distance and relatedness. Product distance and relatedness has emerged as a transformative framework for understanding economic development patterns through the Product Space network. Products are interconnected based on shared production capabilities, which ultimately reveals an uneven structure where complex products form a densely connected core while simpler products remain at the periphery (Hidalgo et al., 2007). This network structure explains why countries positioned near the dense core find it easier to diversify and upgrade their economies, while those at the edge face greater challenges in economic transformation.

Product distance analysis provides crucial insights for developing economies seeking diversification pathways. In the case of Paraguay's economic development challenges, understanding product relatedness can guide strategic diversification emphasizes the importance of targeting products that are both within reach of current capabilities and offer potential for higher income and complexity, which accentuates how product distance considerations can help shape more effective development strategies (Hartmann et al., 2019). Furthermore, the impact of product relatedness extends significantly to regional economic development, as evidenced by innovative methodological adaptations. In a study conducted in Italy, it was found that regions occupying central positions in the Product Space network achieve higher growth and innovation rates duet o enhanced knowledge transfer opportunities (Cicerone et al., 2020).

The relationship between product distance and local industrial development follows distinct patterns at the regional level. Boschma et al. (2013)'s analysis of Spanish regions revealed that new industries are more likely to emerge when they share capabilities with existing local industries, rather than drawing on national-level capabilities. This finding emphasizes how product relatedness at the local level shapes regional industrial evolution. On top of that, product relatedness interacts significantly with geographic proximity to influence economic development. Through a study of Indonesian manufacturing firms, relatedness-mediated spillovers from multinational enterprises enhance domestic firm productivity within specific geographic ranges, with effects varying by firm size. Their research demonstrates how product relatedness combines with spatial proximity to facilitate knowledge transfer and productivity improvements (Cortinovis et al., 2021).

Product relatedness fundamentally shapes the pathways of economic evolution and diversification potential that is crucial for Indonesia's provincial level green transition strategies.

Boschma et al. (2013) research established that regions with more interconnected industrial structures face lower barriers to diversification, as the shorter distance between existing and potential new products reduces the resources required for economic transformation. This insight provides a crucial framework for understanding how product distance influences regional economic resilience and adaptability.

Green Complexity

The main theme of this paper is an extension of the economic complexity concept, which is the green complexity. Green complexity is a specialized framework within economic complexity theory that offers crucial insights into countries' capabilities to produce sophisticated, sustainable goods. GCI provides valuable perspectives on the intersection of environmental sustainability and economic development, highlighting connections between green production capabilities, economic growth, inequality, emissions reduction, and sustainable industry development globally.

The foundational conceptualization and measurement of green complexity have established its strong correlation with technological advancement and environmental performance. GCI demonstrates that countries with high GCI scores typically possess advanced technological capabilities and lower emissions intensity (Mealy & Teytelboym, 2022). In another study, Andres & Mealy (2021) utilized the Green Transition Navigator to analyze G7 nations, revealing Germany and Italy's leadership in green production capabilities while highlighting China's rapid advancement through strategic investments in renewable technologies.

Green complexity ultimately should have an effect on environmental aspects, hence, the relationship between green complexity and environmental impacts itself have been examined by several studies as well. For instance, the relationship between green complexity and emissions reduction varies significantly across different economic development levels. While green complexity shows a strong negative correlation with CO_2 emissions in developing economies, this relationship becomes neutral in high-income countries where green practices are already integrated into production structures Tokpunar & DALGIÇ (2024). Such as in the context of U.S. states, broader economic fitness, rather than green complexity alone, serves as a more powerful driver of emissions reductions through industrial diversification and energy efficiency measures Çnar et al. (2023). On the other hand, developing economies like Indonesia and Vietnam exceed expectations in green exports relative to their complexity levels (McKay, 2023). Regional disparities within countries also play a crucial role, as demonstrated by Montiel-Hernández et al. (2024) in their study of Mexico, where northern states show greater potential for green growth compared to their southern counterparts due to higher complexity levels.

On top of that, the socioeconomic dimensions of green complexity show important connections to inequality and human capital development, high income inequality hampers green inventive capacity, particularly affecting access to complex green technologies (Napolitano et al., 2022). Complementing this finding, Neagu & Neagu (2024) demonstrated in their study of Central and Eastern European countries that the combination of economic complexity and human capital development significantly advances green development initiatives. Liu et al. (2021) add further evidence by showing that in the Lancang-Mekong Cooperation (LMC) countries, economic complexity reduces fossil fuel consumption, further supporting green economic goals.

Recent research has expanded the analytical framework of green complexity to include multiple dimensions and sector-specific applications. Stojkoski et al. (2023) developed a comprehensive model incorporating trade, technology, and research complexities, demonstrating that inclusive green growth flourishes best when complexity is high across all dimensions. In the context of ASEAN nations, Y. Zhao et al. (2024) revealed that sector-specific green development, particularly in industrial and agricultural sectors, effectively reduces fossil fuel dependence.

The practical implications of green complexity extend significantly into labor markets and institutional frameworks. For instance, in Brazil, regions with higher economic complexity show greater potential for green job creation, highlighting the path-dependent nature of green employment growth (Dordmond et al., 2021). Wang & Yang (2022) added another crucial dimension to this understanding by showing that institutional quality plays a vital moderating role in the relationship between green complexity and emissions reduction, particularly in developing economies. Furthermore, green innovation and natural resource management, particularly in the G7 countries, are crucial drivers for reducing carbon emissions in complex economies (Safi et al., 2023).

Several studies have proposed novel measures to enhance the ECI framework for sustainability assessments. Cakir et al. (2021) introduced a model that combines export and import data within the Economic Complexity Index, capturing a broader understanding of internal economic resilience and sustainability. Similarly, Rafique et al. (2022) emphasized the ecological footprint as a measure of environmental impact in complex economies, identifying renewable energy and human capital investment as key factors in mitigating ecological degradation. Sušnik et al. (2019) took an ecological economics approach, proposing that structural diversity driven by knowledge and resource efficiency plays a fundamental role in achieving sustainable growth.

Studies exploring regional and sectoral applications of green complexity have also provided additional insights. In a study that analyzes the Environmental Kuznets Curve (EKC) hypothesis within GCC countries, finds that higher economic complexity initially raises environmental degradation but later contributes to environmental improvement as economies reach higher complexity thresholds (ElMassah & Hassanein, 2023). Neagu (2020) found that the ecological footprint is significantly impacted by fossil fuel consumption in complex economies, with advanced economic structures linked to higher environmental costs due to increased resource use. There is also a non-linear relationship between resource dependency and sustainability, suggesting that economic complexity can mitigate environmental impacts in the Emerging Seven (E7) economies through resource-efficient practices Cong & Ren (2023).

On a broader context, the integration of structural complexity and knowledge growth has been further supported by studies like that of Aerni (2021), which examined Switzerland's decentralized economic model. This research highlights how regional economic ecosystems, supported by SMEs and entrepreneurial migrants, contribute to sustainable and inclusive growth outside of urban centers. Lastly, research found that economic complexity and education quality significantly enhance environmental sustainability in MENA countries, which highlights the role of human capital development and policy measures for long-term ecological balance (Saud et al., 2023).

C. RESEARCH METHODS

Data

This study utilizes a comprehensive dataset compiled from various international and national sources. To ensure the exhaustiveness of the green product definition, primary data sources include the International Monetary Fund (IMF), Organisation for Economic Co-operation and Development (OECD), and World Trade Organization (WTO). From these sources, thie study identified and compiled data on 493 green products, classified at the 6-digit Harmonized System (HS) code level. These green products are categorized into four main groups: renewable energy, pollution management, clean technologies, and resource management.

Green products, as defined by these organizations, refer to goods and technologies that have a reduced environmental impact or contribute to environmental protection and sustainability through its potential or existing environmental impacts. Renewable energy products include solar panels, wind turbines, biofuel technologies, and its related upstream products required to produce these. Pollution management products encompass air and water filtration systems, waste treatment equipment, and its upstream products. Clean technology products involve energy-efficient appliances, electric vehicles, smart grid technologies, and its upstream products. Resource management products include recycling equipment, water conservation systems, sustainable forestry tools, and its upstream products. However, it needs to be noted that majority of these products are not necessarily an end product that has environmental impact, rather are those that if used for clean technologies or environmental purposes, they would have significant environmental impacts.

The calculation of economic and green complexities would require the calculation of provinces' trade competitiveness, which is reflected by their Revealed Comparative Advantage (RCA). To calculate the RCA for each HS code at both the provincial and global levels, we employed data from the World Integrated Trade Solution (WITS) and export-import data from Indonesia's *Badan Pusat Statistik* (BPS). The study encompasses all 34 provinces of Indonesia, in addition to 226 countries globally, aiming to treat these provinces and countries as 260 economies overall. The analysis is based on 2022 trade data, which offers the recent snapshot of Indonesia's green economy landscape. This temporal focus allows for an up-to-date assessment of the country's economic complexity and green product competitiveness.

Economic Complexity Indeks

To measure economic complexity, we employ the methodology developed by Hausmann and Hidalgo (2009). The Economic Complexity Index (ECI) is calculated using the following steps:

1. Calculate the Revealed Comparative Advantage (RCA) for each product in each province:

$$RCA_{cp} = \frac{x_{cp} \ / \ \sum_p x_{cp}}{\sum_c x_{cp} \ / \ \sum_{c,p} x_{cp}}$$

where x_{cp} is the export value of product p by province c.

2. Create a binary matrix $M_{cp}$where $M_{cp} = 1$ if $RCA_{cp} \geq 1$, and 0 otherwise.

3. Calculate diversity ($k_{c,0}$) and ubiquity ($k_{p,0}$):

$$k_{c,0} = \sum_p M_{cp}$$

$$k_{p,0} = \sum_c M_{cp}$$

4. Calculate $k_{c,N}$ and $k_{p,N}$ iteratively:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} \cdot k_{p,N-1}$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_{p} M_{cp} \cdot k_{c,N-1}$$

5. The ECI is defined as the eigenvector associated with the second largest eigenvalue of the matrix

$$\widetilde{M_{cc'}} = \sum_{p} \frac{M_{cp} M_{c'} p}{k_{p,0} k_{c,0}}$$

Green Complexity Index

The Green Complexity Index (GCI) is derived from the Economic Complexity Index but focuses specifically on green products. We calculate the GCI for each province as follows:

1. Identify the set of green products G (493 products in our dataset, categorized into renewable energy, pollution management, cleantech, and resource management).

2. Calculate the Product Complexity Index (PCI) for each product using the method analogous to ECI calculation.

3. For each province, sum the PCI of green products in which the province has a comparative advantage:

$$GCI_c = \sum_{p \in G} PCI_p \cdot I(RCA_{cp} \geq 1)$$

where $I(\,)$is an indicator function that equals 1 if the condition is true, and 0 otherwise.

Product Distance

To measure the distance between products, we use the approach developed by Hidalgo and Hausmann (2009). The product distance is calculated as follows:

1. Calculate the conditional probability of co-exporting products:

$$\phi_{i,j} = \frac{\sum_c M_{ci} M_{cj}}{\max\,(k_{i,0}, k_{j,0})}$$

where M_{ci} and M_{cj} are entries in the binary matrix M for products i and j.

2. The distance between products i and j is then defined as:

$$d_{i,j} = 1 - \phi_{i,j}$$

This measure of product distance allows us to map the product space and identify potential pathways for diversification into green products for each province, considering the four categories of green products: renewable energy, pollution management, cleantech, and resource management.

D. RESULTS AND DISCUSSION

Our analysis of the economic complexity index (ECI) and green complexity index (GCI) across various Indonesian provinces reveals patterns and regional disparities. The results demonstrate a comprehensive overview of Indonesia's economic and green economy landscape, which highlights both areas of strength and potential for development in the green economy sector.

Green Product Exports

Nationally, Indonesia exports a wide range of products that correspond with the criteria of green products in this study. Indonesia's highest green product export is from liquefied natural gas (HS Code: 271111) with an export value of USD 5 billion, followed by a range of products such as small and medium sized cars, as well as ammonia and electrical machines, as illustrated in Figure 2.

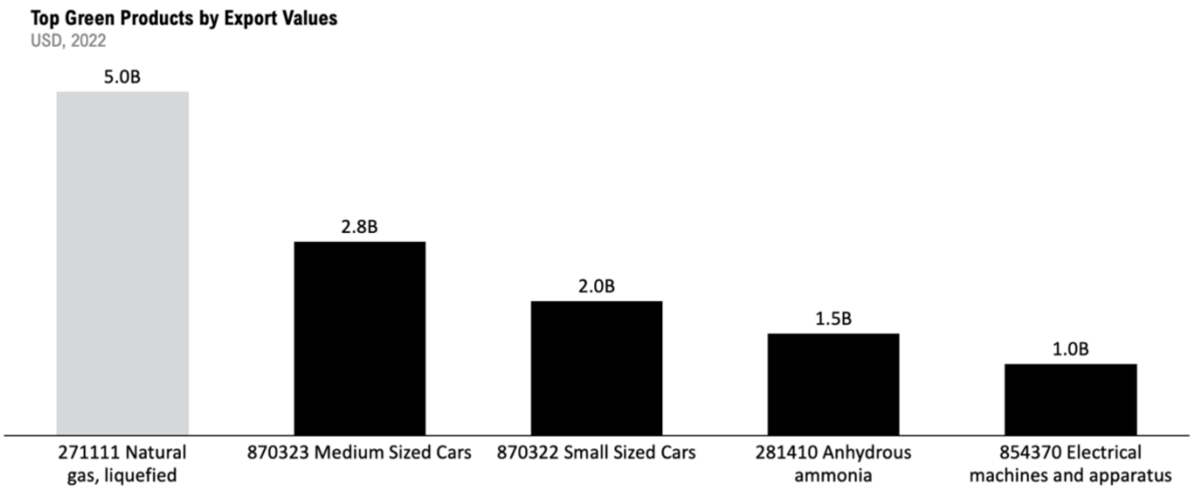

Figure 2. Top Green Products by Export Values

However, high green product export values does not guarantee its competitiveness in the global market. Indonesia's competitive products within the green product realm include brooms or brushes of vegetable material (HS Code: 960310) with an RCA of 172,43, followed by a range of other products including ether-phenols, ammonia, motorcycle, and pipe-line submerged arc welded steel, which is shown in Figure 3.

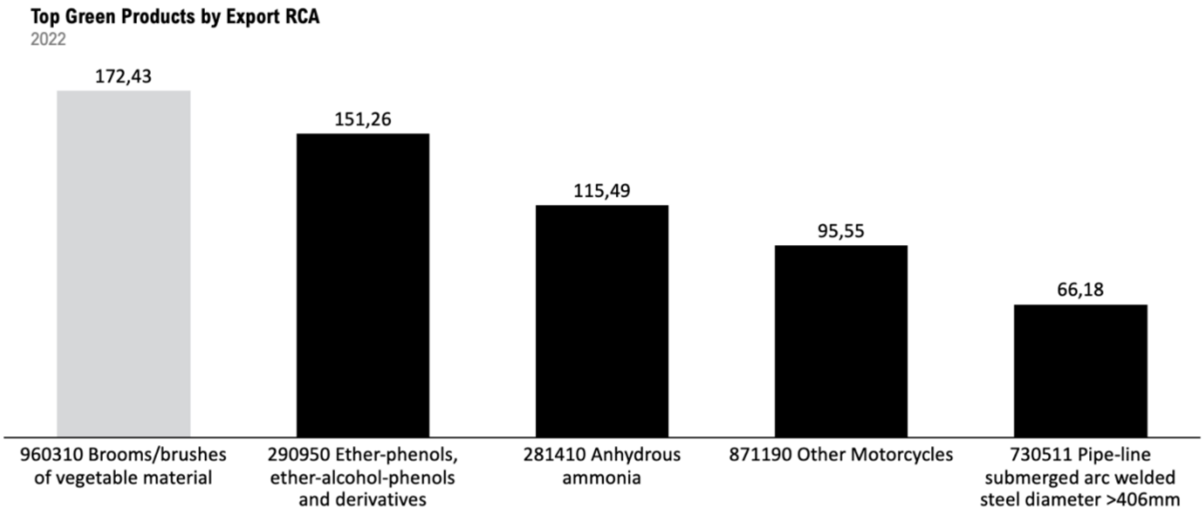

Figure 3. Top Green Products by Export RCA

Provincially, we show that green product exports across Indonesian provinces reveals significant disparities, as illustrated in Figure 4. DKI Jakarta stands out as the leader, exporting approximately 370 green products with a total export value of USD 7,3 billion, which showcases its diverse and advanced potential for green economy. This aligns with Jakarta's role as the country's capital and major economic hub, yet also related with it being one of the main export ports for other provinces. Following DKI Jakarta, other provinces including Kalimantan Timur, Papua Barat, Kepulauan Riau, and Sulawesi Tengah, are also amongst the top provinces for green products.

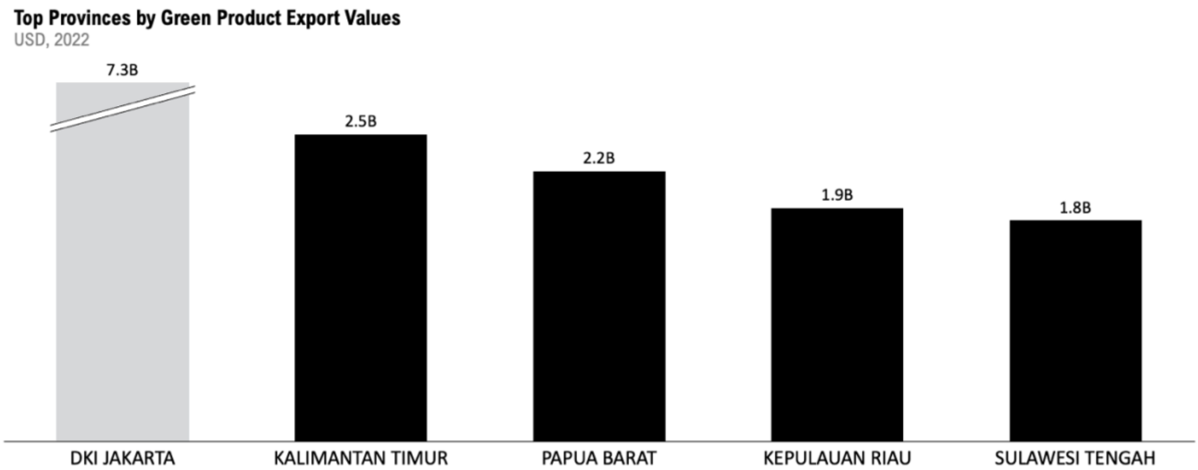

Figure 4. Top Provinces by Green Product Export Values

Figure 5 provides further insight by showing the number of competitive green product exports for each province. Competitiveness is determined by having a Revealed Comparative Advantage (RCA) greater than or equal to 1. DKI Jakarta maintains its leading position with approximately 49 competitive green product exports. Jawa Barat and Nusa Tenggara Timur follow closely, each with about 38 and 36 respective competitive green products. Jawa Timur and Jawa Tengah round out the top five, exporting roughly 23 and 13 competitive green products respectively.

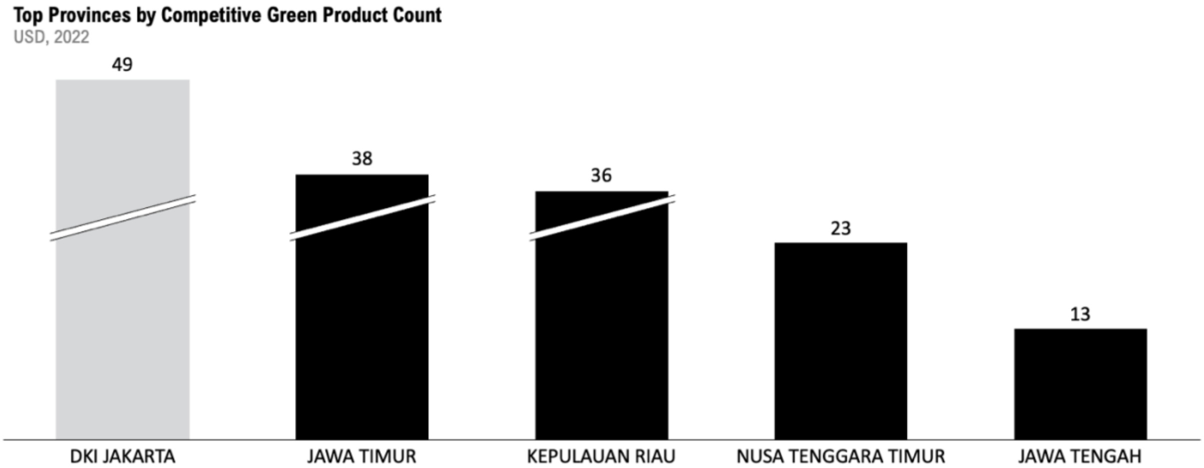

Figure 5. Top Provinces by Competitive Green Product Count

Upon looking at green products in general, analyzing green product exports by product type is also an essential lense. For renewable energy, Kepulauan Riau exports the highest with a total value of USD 1,2 billion. For pollution management, DKI Jakarta exports a total of USD 5,2 billion, surpassing other provinces such as Jawa Barat, Jawa Timur, Kepulauan Riau, and Sumatera utara. Another green product type is resource management, whereby is led by Kalimantan Timur, with a total export value of USD 0,8 billion. Lastly, clean technology is led by Papua Barat, with a total export value of USD 2,2 billion.

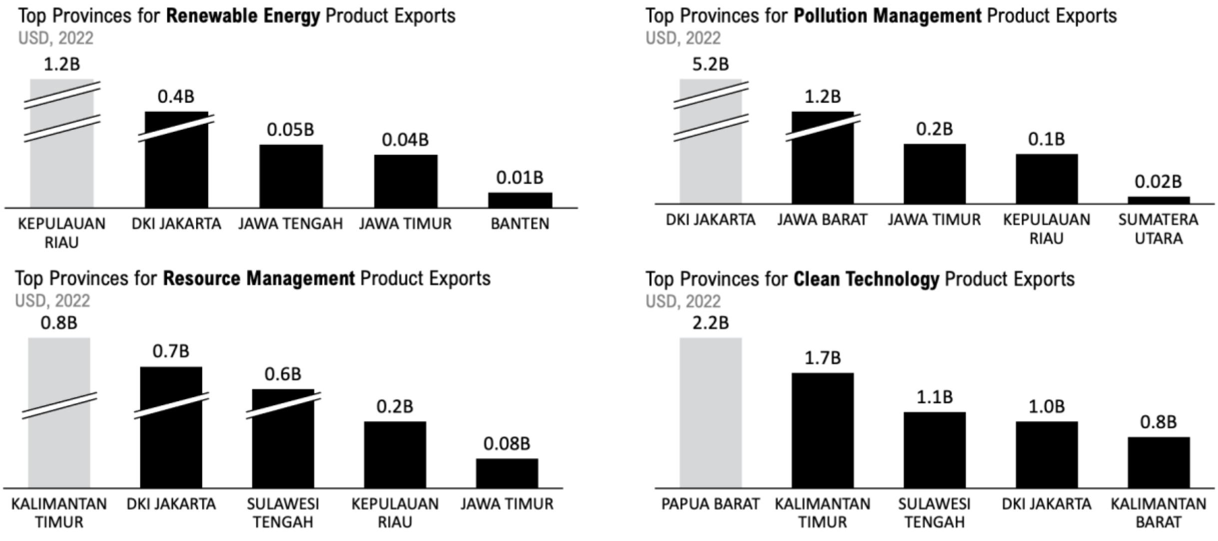

Figure 6. Top Provinces by Green Product Exports, breakdown by Product Types

Green Complexity and Economic Complexity

To evaluate Indonesia's capabilities in green product development, it is essential to consider the country's economic complexity within both general and green economic contexts. Complexity indices measure a nation's productive capabilities in manufacturing sophisticated products. Before exploring Indonesia's green complexity index—which specifically reflects its capacity to develop green products—it is crucial to first examine the overall economic complexity of the country.

Among Indonesia's provinces, Jawa Barat, Banten, and Kepulauan Riau exhibit the highest Economic Complexity Index (ECI). DKI Jakarta, for instance, exports a variety of sophisticated products, including mechanical shovels, excavators, and shovel loaders equipped with a 360-degree revolving superstructure (HS Code: 842952). Additionally, the province exports vehicles that feature spark-ignition internal combustion reciprocating piston engines with cylinder capacities exceeding 1500cc but not surpassing 3000cc (HS Code: 870323). Another significant export from DKI Jakarta is flat-rolled iron or non-alloy steel, which is not in coils, has a width of 600mm or more, is hot-rolled without patterns in relief, and possesses a thickness exceeding 10mm (HS Code: 720851).

Banten province specializes in exporting cyclic hydrocarbons, such as styrene (HS Code: 290250), and acyclic hydrocarbons, including unsaturated butene (butylene) and its isomers (HS Code: 290123). Furthermore, Banten exports flat-rolled iron or non-alloy steel in coils without patterns in relief, with a width of 600mm or more, hot-rolled, pickled, and with a thickness ranging between 3mm and 4.75mm (HS Code: 720826).

Kepulauan Riau showcases a diverse range of exports, including machines and mechanical appliances for treating metal, such as electric wire coil-winders (HS Code: 847981). The province also exports silicones in their primary forms (HS Code: 391000) and electrical apparatus, including thyristors, diacs, and triacs, excluding photosensitive devices (HS Code: 854130).

This detailed analysis underscores the sophisticated and diverse export capabilities of Indonesia's leading provinces, highlighting the country's robust foundation for advancing green product development. By understanding the existing economic complexities and the specific high-value products each province specializes in, stakeholders can better identify opportunities and areas for growth within Indonesia's green economy.

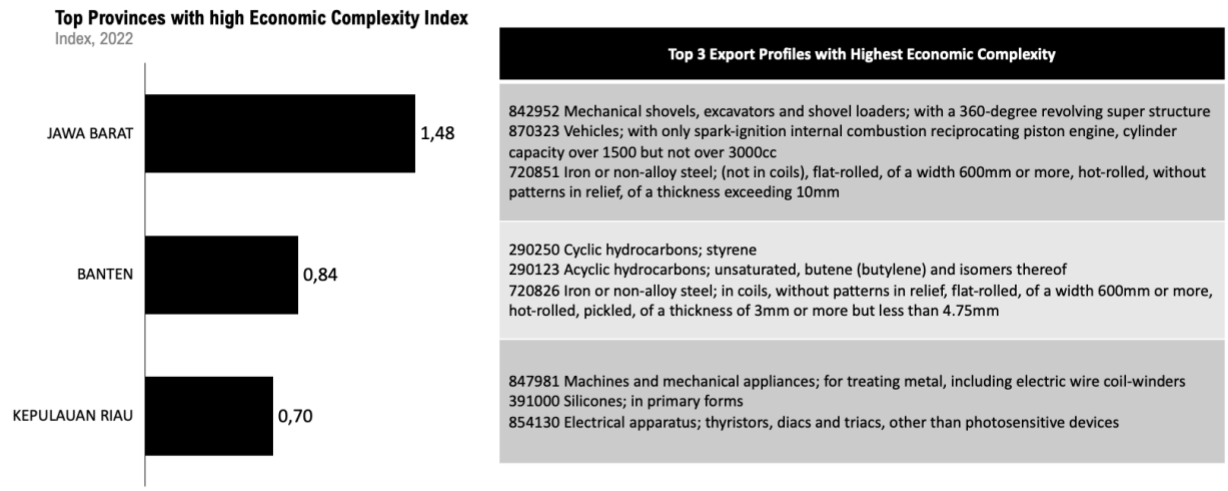

Figure 7. Top Provinces with High Economic Complexity Index

From the point of view of green complexity, Indonesia's provinces are led by DKI Jakarta, Kepulauan Riau, and Jawa Barat. In breaking down by product type, DKI Jakarta has the highest green complexity contribution from clean technology (6,32), same goes for Kepulauan Riau (8,34). Meanwhile for Jawa Barat, the greatest contribution is from renewable energy (2,86).

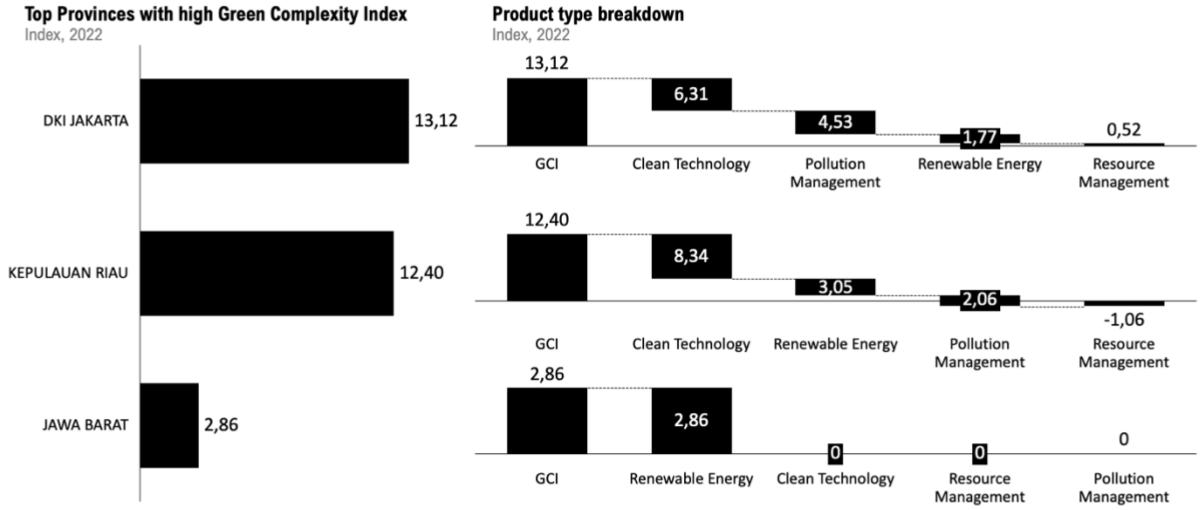

Figure 8. Top Provinces with High Green Complexity Index

The relationship between Economic Complexity Index (ECI) and Green Complexity Index (GCI) across Indonesian provinces also reveals interesting patterns, as illustrated in Figure 9.

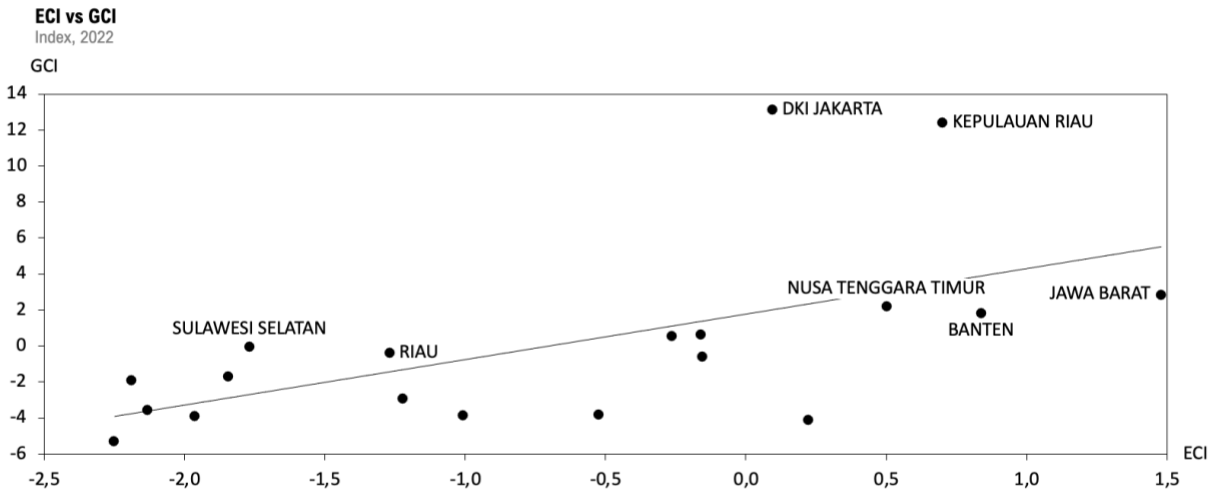

Figure 9. ECI and GCI comparison

Figure 9, which shows the relationship between ECI and GCI shows a linear positive patterns. There appears to be a weak positive correlation between ECI and GCI, suggesting that provinces with higher economic complexity tend to have slightly higher green complexity. Among all provinces in Indonesia, Jawa Barat has the highest ECI (1,48) and third highest GCI (2,86). Meanwhile Kalimantan Timur has the lowest ECI (-2,25), with the lowest GCI (-5,28) as well. The results showcase these provinces contrasting capabilities in transitioning towards green and more sustainable economies. The right panel presents ECI vs GCI rank, which shows a similar weak positive trend. This indicates that provinces ranked higher in economic complexity tend to rank somewhat higher in green complexity as well, but again, the relationship is not strong.

These findings highlight the complex nature of green economic development in Indonesia, indicating that while there is some relationship between overall economic complexity and green complexity, other factors likely play significant roles in determining a province's green economic capabilities. Table annex 1 presents an overview of economic and green complexity indicators across Indonesian provinces, which offers valuable insights into the economic structure and green economy potential of different regions. The data reveals significant variations in economic complexity and green economic activities among provinces, which highlights both opportunities and challenges in Indonesia's economic landscape.

The Economic Complexity Index (ECI) values demonstrate a contrast between provinces. Jawa Barat leads with the highest ECI (1,48), followed by Banten (0,84) and Kepulauan Riau (0,70). However, many provinces, particularly those outside Java, show negative ECI values, with Bengkulu having the lowest (-3,60). This disparity indicates a concentration of economic complexity in certain regions, particularly in Java and nearby provinces, suggesting a need for targeted economic development strategies in less complex economies. A high economic complexity index indicates that the provinces' existing production capabilities as proxied by their export competitiveness are capable of producing sophisticated and complex products. On the other hand, provinces with negative economic complexities indicate that these provinces have limited export diversification and its unsophisticated export profiles. These provinces can move up to more complex economies by expanding their export profiles to include more sophisticated goods.

The Green Complexity Index (GCI) values reveal interesting patterns that do not always align with the ECI rankings. DKI Jakarta has the highest GCI (13,12), closely followed by Kepulauan Riau (12,40). There is a significant drop-off after these two leaders, with the next highest being Jawa Barat at 2,86. Many provinces show zero or negative GCI values, indicating a lack of green economic activities or challenges in transitioning to a green economy. This suggests that while some provinces are making an effort in green economic development, others are lagging behind, potentially due to a lack of resources, infrastructure, or policy support.

The data highlights significant regional disparities, with Java and priority provinces (such as Kepulauan Riau) generally showing higher ECI and GCI values. Eastern provinces, particularly in Kalimantan, Sulawesi, and Papua, often show lower or negative values across multiple indicators. This disparity suggests a need for targeted policies to promote economic complexity and green economic activities in less-developed regions, potentially through infrastructure development, skill-building initiatives, and incentives for green industries.

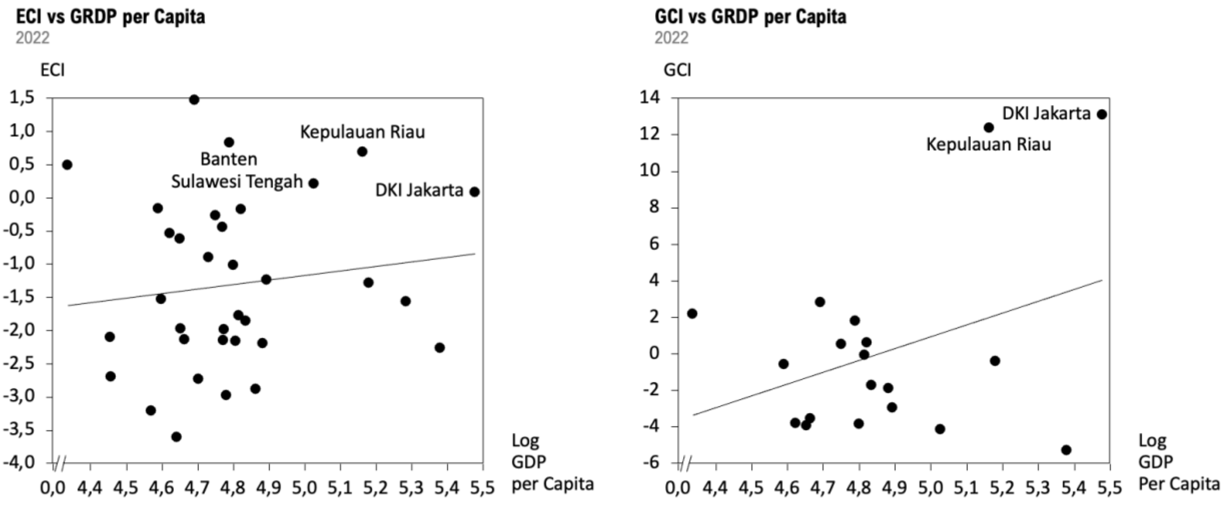

Figure 10. Log GDP per Capita vs ECI and GCI

Our analysis extends beyond the relationship between Economic Complexity Index (ECI) and Green Complexity Index (GCI) to include the connection between GCI and GRDP (Gross Regional Domestic Product) per capita. This additional dimension provides a more comprehensive view of the green economy's development across Indonesian provinces.

Figure 10 illustrates the relationship between the logarithm of GDP per capita and GCI. The scatter plot reveals a positive trend, suggesting that provinces with higher GDP per capita tend to have higher Green Complexity Index scores. This relationship is more pronounced than the one observed between ECI and GCI, which indicates that a province's overall economic output may be a stronger predictor of its green economic complexity than its economic complexity alone.

Interestingly, we observe a cluster of provinces with low GCI scores across a range of GDP per capita levels. This could indicate that some economically diverse or wealthy provinces have not yet fully developed their green sectors, presenting potential opportunities for targeted green economic development.

Some provinces with relatively low GDP per capita have surprisingly high GCI scores, suggesting they have successfully prioritized green industries despite lower overall economic output. Conversely, some high-GDP provinces show lower GCI scores than might be expected, potentially indicating untapped potential in their green sectors, such as Nusa Tenggara Timur.

Green Complexity Index

To further the analysis, we categorized the the GCI into the different green product components, hence deriving the component-specific GCI, which provides a deeper insight into the green economy landscape and the comparison among provinces in terms of green products, as shown in Figure 11.

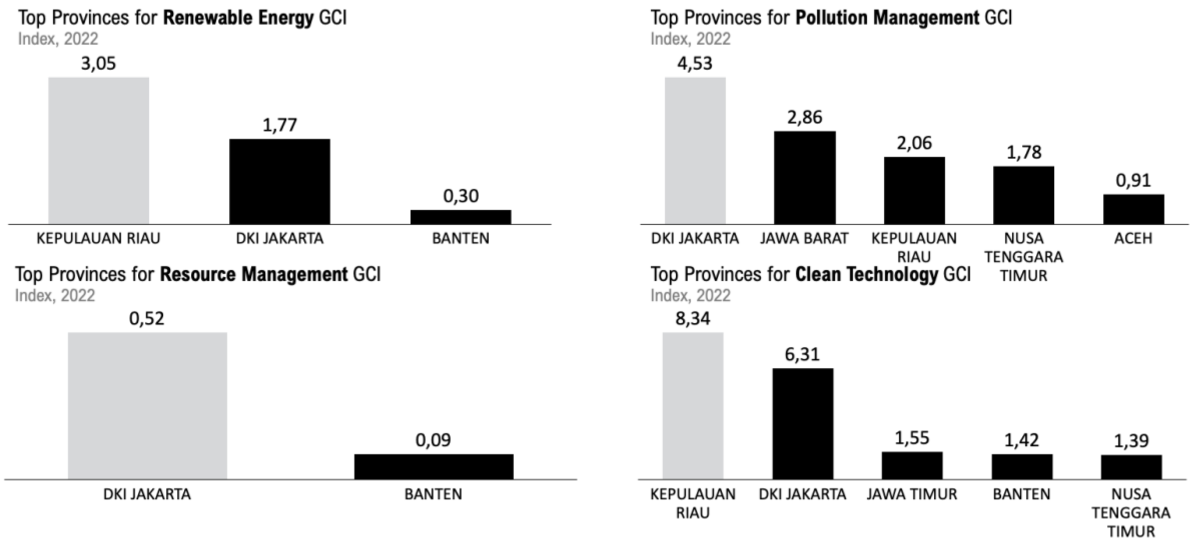

Figure 11. Top Provinces for GCI by Product Type

Renewable Energy

In renewable energy, Kepulauan Riau leads in its GCI for renewable energi of 3.05, followed by DKI Jakarta (1.77), while most provinces have not had competitive exports in renewable energy or its upstream products. This suggests that renewable energy initiatives are concentrated in a few provinces, with many regions yet to develop significant capacity in this sector.

Pollution Management

For pollution management, DKI Jakarta tops the category (4.53), with Jawa Barat (2.86) and Kepulauan Riau (2.06) following. This indicates that these provinces have more advanced pollution control technologies or industries, possibly due to stricter environmental regulations or a higher concentration of industries requiring such technologies.

Resource Management

In resource management, most provinces show negative values, with DKI Jakarta being one of the few positives (0.52). This could indicate challenges in sustainable resource management across most of Indonesia, with only a few provinces showing progress in this area.

Clean Technologies

Clean technology sees Kepulauan Riau with an exceptionally high value (8.34), followed by DKI Jakarta (6.31). This suggests that these provinces have strong capabilities of adopting and possibly producing clean technologies, which could be a significant driver of their overall high GCI scores.

Product Distance

An important follow up question that we highlight in this study is, upon knowing Indonesia's current capabilities, we identify what green products should Indonesia strategically produce next. Using the product distance approach, we identified the most proximate green products from Indonesia's provinces, as shown in the table in Appendix 1. The table provides information on the most proximate products, their distance, and their classification, which offers insights into potential diversification opportunities. Proximate products vary widely across provinces, ranging from electrical components to polymers and industrial equipment. The product classifications span different categories of green complexity, including Pollution Management, Resource Management, and Clean Technologies. For instance, "Parts for diesel and semi-diesel engines" (Sulawesi Selatan) falls under Pollution Management, while "Activated carbon" (Lampung and Kalimantan Barat) is classified as Resource Management.

The distance values are generally high (close to 1) and the feasibility values are generally low (close to 0), indicating that most provinces face challenges in diversifying into these proximate products. DKI Jakarta shows the lowest distance (0,780) to its proximate product (bags and cones of polymers of ethylene), which is classified under Pollution Management, suggesting it has the highest potential for diversification in this green technology area. Interestingly, some provinces share the same proximate product but with different distance values. For example, both Lampung and Kalimantan Barat have "Activated carbon" as their proximate product, but with distances of 0.988, indicating similar challenges in diversification despite being in different regions.

The classification of proximate products provides additional context for potential green economy development. Products like "Liquid dielectric transformers > 10,000 KVA" (Sulawesi Tengah) and "Generating sets, with spark ignition engines" (Riau) fall under Clean Technologies, which indicates potential areas for growth in renewable energy infrastructure.

Discussion

The analysis of regional green complexity across Indonesian provinces reveals several patterns that reflect both local development dynamics and broader theoretical frameworks. Our findings demonstrate distinct regional pathways in green economic development, with each province leveraging different advantages and facing unique challenges in their pursuit of sustainable growth.

DKI Jakarta leads in both total green product exports (370 products) and competitive green exports (48 products) illustrates what Mealy & Teytelboym (2022) identify as the relationship between advanced technological capabilities and green complexity. The province's strong position potentially stems from strategic governmental and fiscal policies, particularly through initiatives like Jakarta Green Investment, which encourages investment in green technologies and infrastructure. The province has successfully leveraged public-private partnerships and green bonds to attract private investment in sustainable infrastructure projects, demonstrating what Lapatinas et al. (2021) describe as the reinforcing relationship between economic sophistication and environmental initiatives.

Kepulauan Riau's value in clean technologies (8,34) and renewable energy (3,05) showcases potentially successful private sector engagement through its Special Economic Zones (KEK). The province's strategy of offering tax incentives and streamlined regulations for green technology investments aligns with the importance of strategic investment frameworks in driving green sector development (Andres & Mealy, 2021). The establishment of KEK Tanjung Sauh demonstrates how regions can create attractive environments for both domestic and international green investments while successfully integrating local and global knowledge networks (B. T. Asheim & Isaksen, 2002).

The weak positive correlation between ECI and GCI across provinces reveals important implications for investment strategies and development patterns. Provinces with higher ECI scores, like Jawa Barat (1.48), have generally been more successful in attracting private investment due to their established industrial base and skilled workforce. However, their relatively lower GCI scores suggest the need for targeted incentives to redirect investment toward green sectors. This pattern aligns with Tokpunar & DALGIÇ (2024) findings about varying relationships between green complexity and development levels.

The sectoral analysis of GCI components reveals distinct investment patterns and opportunities across different environmental domains. In the renewable energy sector, the concentration of capabilities in few provinces indicates substantial untapped investment potential in other regions. Successful provinces have implemented feed-in tariffs and power purchase agreements to attract private renewable energy investment, supporting what Safi et al. (2023) identify as the importance of targeted innovation in driving sustainable development. Jakarta's leadership in pollution management (4,53) has been supported by environmental compliance requirements driving private sector investment in cleaner technologies, while industrial parks in Jawa Barat (2,86) have attracted investment through shared environmental management facilities.

The predominantly negative resource management values across provinces suggest significant investment requirements in circular economy initiatives. Progressive regions have implemented waste-to-resource projects through public-private partnership frameworks, demonstrating what Saad et al. (2023) describe as the potential for resource-dependent economies to build complex green capabilities. This transformation requires substantial private sector engagement and innovative financing mechanisms to overcome initial investment barriers.

Analysis of product distance and proximate products reveals crucial insights for investment attraction strategies. The generally high distance values (close to 1) for most proximate products indicate the need for risk-sharing mechanisms and government guarantees to attract private investment in new green sectors. However, Jakarta's lower distance (0,780) to pollution management products suggests what Boschma et al. (2013) identify as reduced barriers to diversification due to existing related capabilities. This understanding can help provinces develop targeted investment attraction strategies that build on their current strengths while pushing toward greater environmental sustainability.

These findings suggest the need for comprehensive policy approaches to investment attraction and green development. Provinces must develop region-specific investment incentives based on their GCI scores and development potential, while simultaneously strengthening environmental governance to increase investor confidence. The implementation of risk-sharing mechanisms for pioneering investments in new green sectors, coupled with streamlined permitting processes, can help overcome initial market barriers. Furthermore, investment in technical and vocational training, establishment of green technology research centers through university-industry partnerships, and fostering of international collaboration can build the necessary human capital base for sustainable development.

The varying levels of success in developing green complexity across Indonesian provinces reflect what K. Zhao et al. (2021) term as the complex relationship between resource endowment and green development. Success in attracting private investment appears closely tied to what Stojkoski et al. (2023) describe as the multidimensional nature of green growth, requiring coordinated efforts across policy, finance, and institutional frameworks. The analysis suggests that provinces must develop comprehensive investment attraction strategies that consider local capabilities, institutional strength, and specific sectoral opportunities while addressing both economic and environmental objectives.

This research indicates that the path toward green economic development requires a nuanced understanding of regional contexts and capabilities. Future policy development should focus on creating enabling environments that facilitate private investment while ensuring environmental sustainability. The success of provinces like Jakarta and Kepulauan Riau demonstrates that with appropriate policy frameworks and investment mechanisms, regions can successfully transition toward more sustainable and complex green economies.

E. CONCLUSION

Key Findings

This study provides the first comprehensive analysis of green complexity at the provincial level in Indonesia, revealing significant regional disparities and development patterns. Our research reveals substantial variations in green complexity across Indonesian provinces, with DKI Jakarta leading in overall green product exports (370 products) and competitive green exports (49 products), followed by other major provinces like Jawa Barat and Jawa Timur. This pattern suggests a concentration of green production capabilities in more developed regions.

The relationship between Economic Complexity Index (ECI) and Green Complexity Index (GCI) shows a weak positive correlation, indicating that while higher economic complexity somewhat corresponds with greater green complexity, the relationship is not deterministic. This is exemplified by Jawa Barat, which leads in ECI (1,48) but ranks third in GCI (2,86). This finding suggests that green complexity development follows distinct patterns that may diverge from traditional economic development pathways.

Our sectoral analysis reveals specialized capabilities across different green sectors. Kepulauan Riau demonstrates leadership in renewable energy (3,05) and clean technologies (8,34), while DKI Jakarta excels in pollution management (4,53). These specializations suggest the emergence of regional green industry clusters, highlighting how provinces have developed distinct environmental competencies based on their existing industrial base and policy priorities.

The analysis of product distance reveals that most provinces face significant barriers to diversification into new green products, as indicated by generally high product distance values (close to 1). However, some provinces, notably DKI Jakarta with its lower distance values (0,780), show greater potential for green sector diversification. This variation in product distance suggests that provinces face different challenges and opportunities in expanding their green production capabilities.

Policy Implications

Our findings suggest several important policy implications for promoting green economic development across Indonesia. In line with the two-step strategy outlined in the diagram—beginning with Existing Capabilities and advancing toward Green Transition Potentials—policymakers should develop province-specific strategies that account for each region's export profiles, green export profiles, and global demand. This involves identifying which green products are within the nearest “distance” to a province’s industrial and resource base (often referred to as “Smart Bets”) and assessing the feasibility of local renewable energy potential and infrastructure needs. Customized incentive schemes, targeted infrastructure investments to support green industry clusters, and the establishment of regional innovation hubs for specific green technologies are key steps to ensure these strategies are effectively implemented.

Building on these existing capabilities, the creation of knowledge transfer mechanisms emerges as a crucial priority for bridging gaps in green capabilities across provinces. By leveraging the strong points of advanced provinces and sharing them with regions that have yet to develop robust green export profiles, inter-provincial cooperation programs, technical assistance partnerships, and joint research and development initiatives can help accelerate learning. These initiatives will enable provinces to identify and meet global demand for new green products, thereby enhancing their competitiveness in the international market.

A core aspect of Green Transition Potentials relates to green finance innovation, where policymakers must shape financial instruments tailored to regional conditions. This could include province-specific green bonds, regional green investment funds, and risk-sharing mechanisms that lower barriers to green technology adoption. Such initiatives align with the “Key Enablers” highlighted in the diagram—especially green financing—and help ensure that even provinces with limited resources can access the necessary capital to develop promising green industries.

Equally important is capacity building. Programs aimed at strengthening human capital and institutional capacity—through technical training aligned with provincial green industry needs, improved environmental governance, and support for green technology research and development—form the foundation for any successful green transition. In line with the diagram’s emphasis on societal awareness and involvement, fostering R&D and innovation will accelerate the adoption of cleaner solutions while ensuring equitable benefits for businesses, communities, and the workforce. Additionally, comprehensive waste management initiatives at both the business and household levels will amplify the positive impacts of the transition.

Overall, these policy implications underscore the necessity of a holistic approach—one that starts with mapping each province’s Existing Capabilities, identifies promising Green Transition Potentials, and is bolstered by the right Key Enablers. By following this structured pathway and addressing capacity building, financing, and knowledge transfer gaps, Indonesia can effectively unlock its green economic potential and drive sustainable growth across all provinces.

Future Research Directions

This study opens several important avenues for future research. Longitudinal studies tracking the evolution of provincial green complexity over time would provide valuable insights into development patterns and policy effectiveness. Such temporal analysis could reveal how provinces progress along different green development pathways and identify critical factors that influence success.

Detailed evaluation of specific regional policies' impacts on green complexity development would help identify best practices and optimize policy interventions. This research could provide crucial guidance for policymakers seeking to promote green industry development in their regions. Additionally, investigation of knowledge spillovers and technology transfer between provinces could illuminate paths for accelerating green development in lagging regions.

The relationship between provincial green complexity and participation in global green value chains represents another promising research direction. Understanding how provinces integrate into international sustainable production networks could inform export development strategies and help optimize regional industrial policies.

Further research should examine the link between provincial green complexity and concrete environmental improvements as well as the potential for attracting private investments.

Such studies would help validate the effectiveness of green development strategies and ensure that increases in green complexity translate into meaningful environmental benefits. Additionally, investigation of the relationship between green finance availability and provincial green complexity development could inform financial policy design and help optimize resource allocation for sustainable development.

These research directions would contribute to a more nuanced understanding of regional green development dynamics and help refine policy approaches for promoting sustainable economic growth across Indonesia's diverse provinces. The findings would be particularly valuable for policymakers working to balance economic development with environmental sustainability at both provincial and national levels.

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Appendix 1: Indonesia's Provinces and Most Proximate Green Products (Ranked by GCI)

PROVINCE	ECI	GCI	MOST PROXIMATE PRODUCT	DISTANCE	FEASIBILITY	PRODUCT CATEGORY
DKI JAKARTA	0,09	13,12	392321 Bags, cones of polymers of ethylene	0,78	0,22	Resource Management
KEPULAUAN RIAU	0,70	12,40	903090 Parts & accessories, electrical measuring instruments	0,94	0,06	Pollution Management
JAWA BARAT	1,48	2,86	841360 Rotary positive displacement pumps nes	1,00	0,00	Pollution Management
NUSA TENGGARA TIMUR	0,50	2,20	730690 Tube/pipe/hollow profile, iron/steel,riveted/open sea	0,86	0,14	Cealn Technology
BANTEN	0,84	1,81	730511 Pipe-line submerged arc welded steel diameter >406mm	0,99	0,01	Cealn Technology
JAWA TIMUR	-0,16	0,63	392321 Bags, cones of polymers of ethylene	0,87	0,13	Resource Management
BALI	-0,26	0,55	392321 Bags, cones of polymers of ethylene	0,90	0,10	Resource Management
SULAWESI SELATAN	-1,77	-0,06	840999 Parts for diesel and semi-diesel engines	0,99	0,01	Pollution Management
RIAU	-1,27	-0,37	851490 Parts of industrial/etc electric furnaces/ovens nes	0,99	0,01	Pollution Management
ACEH	-0,16	-0,57				
SUMATERA SELATAN	-1,84	-1,70	850220 Generating sets, with spark ignition engines	1,00	0,00	Renewable Energy
JAMBI	-2,19	-1,89				
PAPUA BARAT	-1,22	-2,93				
KALIMANTAN BARAT	-2,13	-3,53	380210 Activated carbon	0,99	0,01	Resource Management
JAWA TENGAH	-0,52	-3,80	960390 Brushes, parts, nes	0,87	0,13	Pollution Management
SUMATERA UTARA	-1,01	-3,84	392321 Bags, cones of polymers of ethylene	0,96	0,04	Resource Management
LAMPUNG	-1,96	-3,89	253090 Mineral substances, nes	0,98	0,02	Resource Management
SULAWESI TENGAH	0,22	-4,11	850423 Liquid dielectric transformers > 10,000 KVA	0,99	0,01	Cealn Technology
KALIMANTAN TIMUR	-2,25	-5,28	890790 Buoys, beacons, coffer-dams, pontoons, floats nes	1,00	0,00	Pollution Management
SULAWESI TENGGARA	-0,43	N/A	850423 Liquid dielectric transformers > 10,000 KVA	1,00	0,00	Cealn Technology
DI YOGYAKARTA	-0,61	N/A				
MALUKU UTARA	-0,88	N/A				
GORONTALO	-1,52	N/A				
KALIMANTAN UTARA	-1,56	N/A	390690 Other acrylic polymers	1,00	0,00	Resource Management
PAPUA	-1,98	N/A	960310 Brooms/brushes of vegetable material	1,00	0,00	Pollution Management
MALUKU	-2,09	N/A				
SULAWESI UTARA	-2,14	N/A				
KEPULAUAN BANGKA BELITUNG	-2,15	N/A				
NUSA TENGGARA BARAT	-2,68	N/A				
SUMATERA BARAT	-2,72	N/A				
KALIMANTAN TENGAH	-2,88	N/A				
KALIMANTAN SELATAN	-2,96	N/A				
SULAWESI BARAT	-3,21	N/A				
BENGKULU	-3,60	N/A				