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Designing the spatial spillovers of sustainable development between the eastern and western countries: Analyzing the integrated sustainability perspective

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ABSTRACT

There are various perspectives of sustainability, including integrated sustainability, weak sustainability, and strong sustainability, complicating the understanding of the perspective fitting the socioeconomic characteristics of each group of countries. To address this research gap, the main objective of the study is to examine the three perspectives of sustainability across the US, China, and Indonesia to reveal their most dominant sustainability perspective. To this end, it maps the spatial spillovers of sustainability pillars, including social, environment, and economy, within the sample countries. For this mapping, this approach estimates the sustainability elasticities using the SEY model, which involves the Vector Autoregression (VAR), simultaneous equations system, and causal examination, within 1974–2020. The results indicate that the elasticities of sustainability are mainly high and synergistic, meaning that the sustainability pillars mainly have considerable and synergistic spillover effects. This finding accepts the integrated sustainability while refusing the perspectives of strong and weak sustainability. Moreover, the findings denote that the flowing patten of spillovers have a spatially symmetric distribution between the US and China, attaching equal importance to the relationships with the western and eastern economies of the world. The theoretical implication of the findings is that they introduce spillovers as the 4th dimension of sustainability, completing the three classical dimensions of economy, environment, and social in the context of the weak and strong perspective of sustainability. From the perspective of policy recommendation, the findings suggest decision-makers in Indonesia to promote peaceful, strong, and balanced ties with the great economic powers in the west and the east like the US and China.

1. Introduction

In recent decades, sustainable development is consistently an important issue in the world as the global community has reached an inclusive agreement on the improvement of sustainable development (Ahmadi et al., 2021; Barron et al., 2023; Hajian and Jangchi Kashani, 2021; Khodaparast Shirazi et al., 2020; Salvia et al., 2019). This agreement defines the developmental process of countries far more than a merely economic development, but a comprehensive development without social, economic, and environmental issues (Kamran et al., 2023; Kerimkhulle et al., 2023; Mohamad Taghvaee et al., 2023; Sadiq et al., 2023). To this end, the United Nations (UN) organization classified sustainability into three pillars involving economy, environment, and social, emerging various perspectives of sustainability in the literature such as the weak, strong, and integrated sustainability (Jeronen, 2023; Simangan et al., 2021; Sharma et al., 2023). Due to the considerable attention of researchers and policy-makers, the UN went beyond the three pillars and proposed a new definition of sustainability with more resolution. This new approach categorizes sustainability into 17 Sustainable Development Goals (SDGs) like a manifesto to define certain targets of sustainability in various dimensions, encouraging different countries to achieve (Fonseca et al., 2020; Kiriveldeniya, 2024; Huang and Akbari, 2024; Möller and Grießhammer, 2024). This framework highlights the importance of the sustainability and its interconnection with the globalization especially for the emerging economies with continuously high economic development like Indonesia.

The economic development in Indonesia shows a considerable and

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continuous growth in recent years, projected to achieve the highest global ranks in the world during the next decades (Al-Fadhat, 2022; Kurniawan and Managi, 2018; Mohamad Taghvaee et al., 2017; Tleubayev et al., 2024; Marantika, A., Hasan, S., Fasa, M. I., & Faizah, 2020). This progress has begun since the transformation of its economy from agriculture and natural resources towards more diverse sectors like services, industry, technology, and finance (Aminullah, 2024; Andriansyah et al., 2023; Hill, H., & Pasaribu, 2024). Currently, its geopolitically strategic location serves as an active, dynamic, and effective factor in the supply chain not only regionally but also globally (Herrero et al., 2023; Iksan & Soong, 2023). In addition, its high population with the dominant share of young labor-force provides a valuable human capital (Adam and Negara, 2015; Neshat Ghojagh et al., 2024; Nodehi and Mohamad Taghvaee, 2022; Wibowo, 2019). The combination of its strategic location, human capital, and natural resources paves the way for an exceptional progress in the industrial activities (e.g., textile, electronics, automotive) and services sector (e.g., tourism, finance, and telecommunications). Therefore, the World Bank predicts Indonesia becoming one of the biggest economies at the global level due to its persistent growth and rich potentials for further development (World Bank, 2024). However, the progressive economic growth increasingly damages the sustainable development in Indonesia from social and environmental aspects (Cai et al., 2025; Marantika et al., 2020; Miller, 2023; Surya et al., 2021). This developmental process accelerates urbanization and industrialization, leading to disparities in various social dimensions, e.g., distribution of income, justice, and access to public services like healthcare and education (Gomez Betancourt & Vallet, 2024; Govender, 2016; Turok and McGranahan, 2013; Kajiita, 2024). In this way, it widens the gaps between different socio-economic and regional classes like rural–urban people, which undermines social cohesion (Liu, 2020; Moustakas, 2023; Nodehi and Taghvaee, 2022a, 2022b; Akram and Perviaz, 2023; Sakketa, 2022). In addition, this economic growth damages the environment by over-extracting the natural resources, destructing the habitats, and producing the pollutant wastes and emissions (Ekonomou & Halkos, 2023; Jain et al., 2023; Mehmood, 2024; Uddin, 2021). These detrimental consequences not only threaten the human health and biodiversity in Indonesia but also exacerbate the climate change and global warming in the world. Thus, the considerable and persistent economic growth in Indonesia brings critical challenges regarding the adoption and adjustment of sustainable development strategies to discover a harmony among economy, society, and environment (Apresian et al., 2019; Pacheco et al., 2017; Sen, 2013; Parsa et al., 2019; Singh et al., 2022; Taghvaee et al., 2022).

In Indonesia, the benefits of economic growth and its destructive impacts on sustainability complicates the adjustment of the relationships with eastern and western countries which follow different approaches to sustainable development. For example, the relationship with China may open effective opportunities for rapid economic growth while lagging behind the global level of social and environmental development. In contrast, the connection with the United States (US) can considerably improve social and environmental development but with an economic development not as rapid as China. Hence, the heterogeneous social, environmental, and economic spillovers of China and the US confuses policy-makers in Indonesia how to adopt balanced and optimal relationships.

Investigating the sustainable development in Indonesia has become necessary due to its recent destructive dynamics of the environmental pollution and socioeconomic issues. For example, its Carbon Dioxide emissions have increased about 15 times from around 47 to 670 million tons each year between 1974–2022, compared with business-as-usual scenario (World Bank, 2024). This increasing trend continues, despite the Indonesia's commitment to reduce the emissions by 29 % unconditionally and 41 % conditionally in 2030 (Government of Indonesia, 2016; Rachmawati et al., 2024; Taghvaee and Hajiani, 2014; Wuwung et al., 2024; Hapsari, 2024). Such detrimental trends are also evident in socioeconomic indicators such as urban–rural gap of access to healthcare facilities, which offers only 5 % of the public health services to rural areas that involve about 48 % of the total population in the recent decade (Anggraini, 2023; Casti, 2021; Liepins et al., 2024; Sutrisni et al., 2023). Hence, these current severely problematic trends of the environmental and socioeconomic indexes substantially necessitate exploration of the social, environmental, and economic aspects of sustainability in Indonesia.

These issues propose the following crucial research questions:

What are the relationships between social, environmental, and economic pillars of sustainability?

How effective are the sustainability spillovers distributed among Indonesia, China, and the US?

To answer these questions and address the problems, this paper aims to map the spillovers of sustainability pillars, including social, environment, and economy, among Indonesia, China, and the US. To this end, it innovatively uses a SEY model to estimate the sustainability elasticities in Indonesia corresponding to those of China and the US. In this way, this approach provides a novel application of the SEY model to examine the integrated sustainability in Indonesia and its relationship with the western and eastern economic powers. It also uniquely the estimated sustainability elasticities to map the spatial spillovers of sustainable development pillars among the sample countries. This estimation originally measures the impacts of spillovers as the fourth pillar of sustainable development from the integrated sustainability perspective.

The results provide theoretical and managerial contributions by examining the integrated sustainability perspective and its spillovers among Indonesia, China, and the US. Theoretically, they uncover how elastic is each sustainable development pillar, corresponding to changes in other pillars. Accordingly, these elasticities can indicate the impacts of each social, environmental, and economic pillar on sustainable development in Indonesia. This comparison can show the more dominant perspective of sustainable development in Indonesia including weak, strong, and integrated sustainability. Regarding managerial contributions, the findings can show policymakers in Indonesia how to establish a balanced development from both national and international outlooks. Regarding the national angle, they can reveal those pillars of sustainable development holding higher serious problems due to suffering from lower attention. This comparison can show which consequences of economic growth require further care to provide a balanced pattern of the steady-state development. From the international outlook, the results of estimating the regional spillovers can indicate which sustainability pillars benefit from strengthening the relationship with the western and eastern economies like the US and China. This map of spillovers can help policymakers balance the international relationships of Indonesia with the western and eastern economic powers to accelerate the economic growth while developing the social and environmental aspects of sustainability.

2. Theoretical framework

Sustainability concept has Three important viewpoints encompassing the weak sustainability, strong sustainability, and integrated sustainability (Barua and Khataniar, 2016; Dietz and Neumayer, 2007; Kiriveldeniya et al., 2024; Ruggerio, 2021). These perspectives define different interconnections within sustainable development framework (involving economy, social, and environment) or sustainability aspects, i.e., people, planet, and prosperity (3Ps) (Cavagnaro and Curiel, 2022; Chin et al., 2023; Gbejewoh, 2021; Makhazhanova et al., 2022; Mohamad Taghvaee et al., 2022).

Fig. 1 illustrates the schema of weak sustainability. According to this figure, the weak sustainability attaches equal importance to each pillar of sustainability. It implies that economic activities are sustainable if their benefits for economic development are greater than their damages to the environmental and social development.

In this regard, many studies have investigated the weak

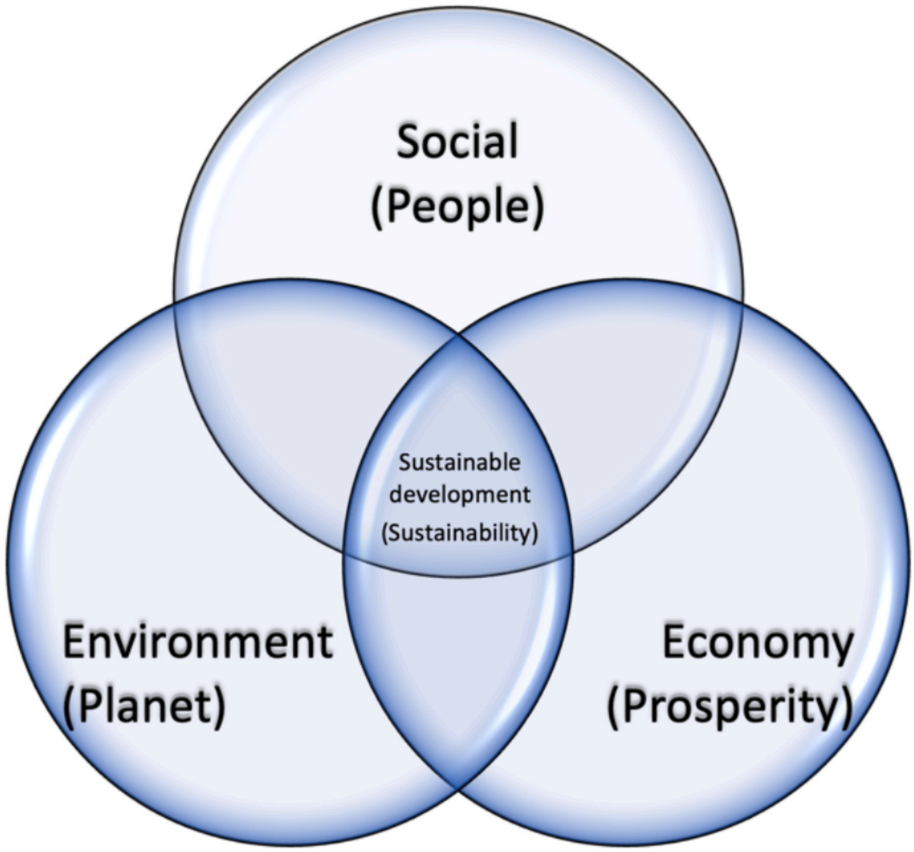

Fig. 1. Perspective weak sustainability
Source: Cai et al., 2025; Nasrollahi et al., 2020; Soretz et al., 2023

sustainability perspective. The previous studies have extensively examined the different perspectives of sustainable development using various models and variables. In this regard, Table 1 selects the recent and relevant studies. For instance, Soretz et al., 2023 introduced a unique definition for the concept of weak sustainability while comparing with the other perspectives of sustainability. They employed the UN scores of sustainability spillovers, life expectancy, and CO2 emissions for the proxies of the sustainable spillovers as well as social, environmental, and economic development within the framework of the SEY model. In addition, Agheli & Taghvaee, 2022 used a Random effects panel model to examined and confirmed the weak sustainability perspective across 43 different Asian countries during 2000–2019. They used political stability, CO2 emissions, and GDP as the proxies of social, environmental, and economic development.

Strong sustainability, similarly, involves a triple framework including economy, social, and environment, but it evaluates the environment dimension as the most crucial (Anselmi et al., 2023; Bonnedahl & Heikkurinen, 2018; Dedeurwaerdere, 2014; Jeronen, 2023a; Nasrollahi et al., 2020). Fig. 2 displays the schema of strong sustainability and its three pillars. Regarding this figure, strong sustainability considers the environmental pillar with higher impacts on the sustainability compared with the other pair of pillars: social and economy (Liang et al., 2024; Otelbaev et al., 2008; Taghvaee et al., 2022; Goh and Chin, 2024; Soretz et al., 2023; V. Taghvaee et al., 2023e). This evaluation order refuses the interchangeable nature of the pillars in weak sustainability (Jeronen, 2023b). In other words, this perspective acknowledges unlimited value for the environment, irreplaceable by social and economic development. Hence, the environmental development has the most crucial impact on sustainability, according to the strong sustainability perspective (Chaaben et al., 2022; Ruggerio, 2021; Mughal and Ramayah, 2020; Mohamad Taghvaee et al., 2022; Uralovich et al., 2023; Genbach et al., 2022).

Correspondingly, some studies have tested the strong sustainability perspective in. different regions. For instance, (Nasrollahi et al., 2020) confirmed this perspective within MENA and OECD countries during 1975–2015, using IPAT and STIRPAT models. They utilized energy efficiency, GDP, and CO2 emissions as the proxies of technological, economic, and environmental aspects of development. Similarly, (V. M. Taghvaee et al., 2022 confirmed the strong sustainability perspective in the transportation sector in Iran within 1979–2016, utilizing the SEY model. They employed life expectancy, CO2 emissions, GDP, and the volume of goods transported to measure social, environmental, economic and transportation dimensions of sustainable development. Subsequently, Soretz et al., 2023; Magazzino et al., 2024; Taghvaee et al., 2023e; Mohebi et al., 2023; Taghvaee et al., 2019 proposed a distinctive definition for the strong sustainability to be distinguished from the other. Sustainability perspectives.

The integrated sustainability pioneers an innovative approach, supplements the spillovers of sustainable development as the fourth dimension to the classic triple-dimension framework of sustainability (Liang et al., 2024; Taghvaee et al., 2023a; Afshari et al., 2023b; Soretz et al., 2023). Fig. 3 illustrates the pattern of flowing spillovers, integrating the dimensions to characterize the integrated sustainability. By this addition, it enhances the comprehensive identity of sustainability from merely three separate elements to an integrated framework cementing the elements with spillovers (Figurek & Thrassou, 2023). Therefore, the integrated sustainability perspective not only adds spillovers to the pillars of sustainable development but also evaluates them as the most effective pillars of sustainability (Afshari et al., 2023a; Cai et al., 2025; Hill and Pasaribu, 2024; Sabatini, 2019; Xiao et al., 2024). Accordingly, it promotes flow-based governance, globalization, and peaceful relationships.

Table 1
Selected studies on examining the different perspectives of sustainability.

Study	Variable	Proxy	Method
(Liang et al., 2024)	• Social development • Economic development • Environmental pollution	• Life expectancy • GDP • CO_2 emissions	SEY model, Simultaneous Equations System
(Huang and Akbari, 2024)	• Social development • Economic development • Environmental pollution	• Life expectancy • GDP • CO_2 emissions	SEY model
(Xiao et al., 2024a)	• Sustainable development spillovers	• UN score	2-stage instrumental variable
Mohamad Taghvaee et al., 2022	• Social development • Economic development • Environmental pollution	• Life expectancy • GDP per capita • CO_2 emissions per capita	SEY model
Taghvaee et al., 2023b	• Social development • Economic development • Environmental pollution	• Life expectancy • GDP • CO_2 emissions	SEY model, Vector AutoRegressive (VAR) and Granger Causality
(Afshari et al., 2023)	• Social development • Economic development • Environmental pollution	• Life expectancy • GDP • CO_2 emissions	SEY model
(Soretz et al., 2023)	• Integrated sustainability • Sustainability spillover • SEY model	• Definition • UN score • Life expectancy CO_2 emissions GDP	Defining the concept
Taghvaee et al., 2023c	• Integrated sustainability • Sustainability spillover • SEY model	• Definition • UN score • Life expectancy CO_2 emissions GDP	Defining the concept
(V. M. Taghvaee et al., 2022)	• Social development • Economic development • Environmental pollution • Transportation	• Life expectancy • GDP • CO_2 emissions • Volumes of goods transported	SEY model, Simultaneous Equations
(Agheli & Taghvaee, 2022)	• Social development • Economic development • Environmental pollution	• Political stability • GDP • CO_2 emissions	Random effects panel model
(Nasrollahi et al., 2020)	• Technology • Economic development • Environmental pollution	• Efficiency • GDP • CO_2 emissions	STIRPAT and IPAT

Recently, the integrated sustainability perspective has been the focus of many studies. For example, Taghvaee et al., 2023b for the first time developed the SEY model to affirm the integrated sustainability perspective at a global level within 1971–2016. They utilized life expectancy, CO2 emissions, and GDP as the proxies of social, environmental, and economic aspects of sustainable development. Similarly, Nodehi et al., 2022 employed the same method and period to accept this perspective in the East Asia and North America. Likely, Mohamad Taghvaee, et al., 2022, 2023 and Liang et al al., 2024 utilized

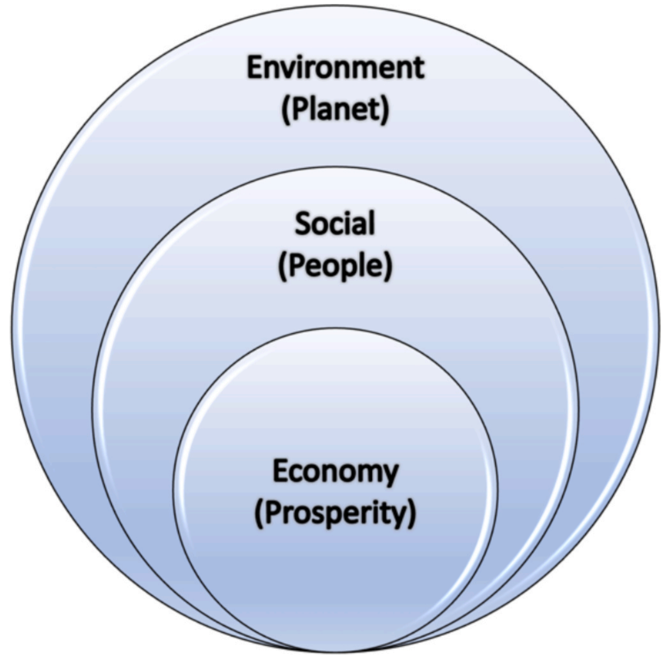

Fig. 2. Perspective of strong sustainability
Source: Cai et al., 2025; Soretz et al., 2023

simultaneous equations system to support this perspective in MENA, Europe, North America, and Asian countries during 1971–2016. All these studies used life expectancy, CO2 emissions, ad GDP as the proxies fo social, environmental, and economic dimensions of sustainable developemtn. In addition, Afshari et al., 2023 used the same model to show the dominance of the integrated sustainability across the US, China, and Iran within 1972–2019. Then, Xiao et al., 2024 used two-stage instrumental variable to accept this perspective across 121 selected countries within 2022–2023. Finally, Huang and Akbari 2024 employed the SEY model to confirm the integrated sustainability in Asian countries. Similarly, all the three mentioned studies have employed life expectancy, CO2 emissions, and GDP as the proxies of social, environmental, and economic aspects of sustainability.

Therefore, there are various studies and theories of sustainability confirmed by other researchers, highlighting a research gap for the dominant sustainability perspective in Indonesia. Comparing these sustainability perspectives proposes a crucial question that the sustainable development in Indonesia follows which pattern of sustainability among the perspectives of weak, strong, or integrated sustainability. This paper addresses this ambiguity by measuring the impacts of these dimensions and their spillovers using the perception of sustainability elasticities and their interactions with the sustainability in the US and China.

3. Methodology

Following Cai et al., 2025; Liang et al., 2024; Nodehi et al., 2022; Taghvaee et al., 2017, 2023c, 2023e; Wang and Taghvaee, 2023, this research estimates the elasticities of sustainability to measure the sustainable development spillovers between Indonesia, China, and the US using SEY model within 1974–2020. The SEY model is an econometric package involving VAR, simultaneous equations system, and Granger causality to estimate the sustainable development elasticities corresponding to the aspects of economy, environment, and social. For this measurement, it presumes that developmental progress of each dimension in Indonesia depends on the sustainability aspects in China and the US. Model 1 defines this assumption.

$$S_i = f(S_j, E_j, Y_j)$$

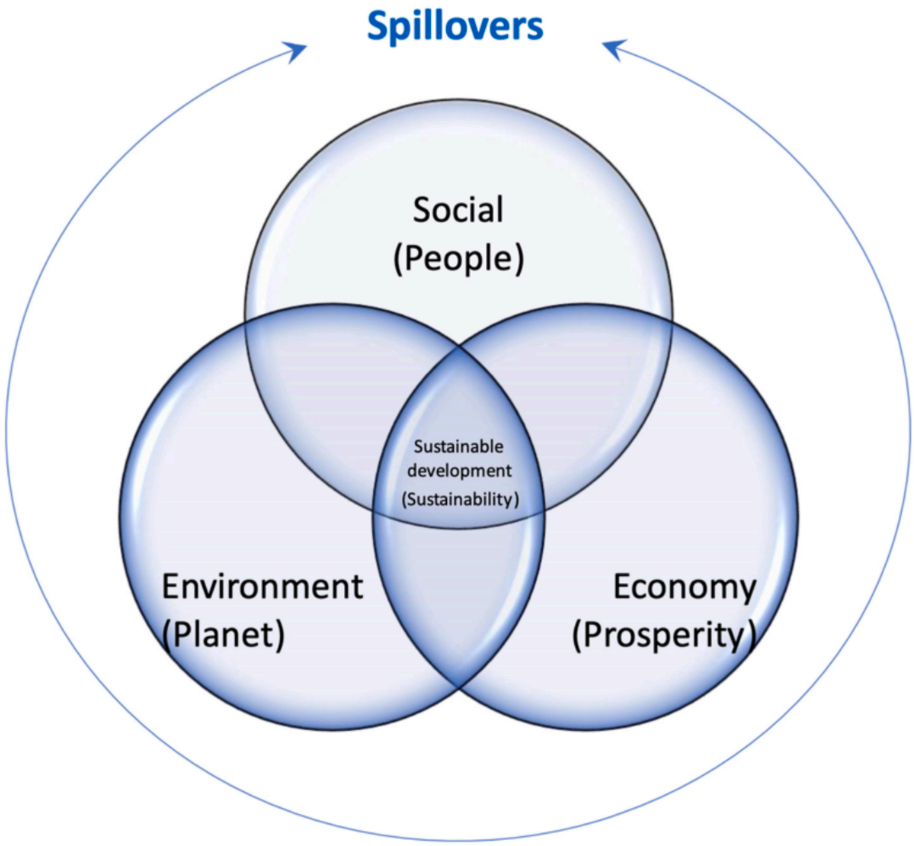

Fig. 3. Perspective of integrated sustainability., 2023.
Source: Cai et al., 2025; Taghvaee et al., 2023d

$$E_i = f(S_j, E_j, Y_j)$$

$$Y_i = f(S_j, E_j, Y_j) \quad (1)$$

where S, E and Y indicate the sustainability aspects encompassing social, environment and economy, respectively, i signifies Indonesia, and j denotes the US and China. This assumption transforms its mathematical format to the following econometric regressions, according to Model 2.

$$LE_{it} = \alpha_{0j} + \alpha_{1j}LE_{jt} + \alpha_{2j}CO^{-1}{}_{jt} + \alpha_{3j}GDP_{jt} + \varepsilon_{1t}$$

$$CO^{-1}{}_{it} = \beta_{0j} + \beta_{1j}LE_{jt} + \beta_{2j}CO^{-1}{}_{jt} + \beta_{3j}GDP_{jt} + \varepsilon_{2t}$$

$$GDP_{it} = \theta_{0j} + \theta_{1j}LE_{jt} + \theta_{2j}CO^{-1}{}_{jt} + \theta_{3j}GDP_{jt} + \varepsilon_{3t} \quad (2)$$

where LE denotes life expectancy, CO^{-1} shows inverse values of CO_2 emissions in per capita, GDP denotes Gross Domestic Production per capita, α, β, and θ are coefficients, their zero-subscribed symbols are intercept, ε represents residual series, t denotes time measured in year. Life expectancy, CO_2 emissions invers, and GDP are indicators for social, environment, and economic development while their coefficients are sustainability elasticities for natural logarithmic values of these variables (Gandhi et al., 2024; Madanizadeh et al., 2023).

This model employs both full and limited information approaches to the estimation of the coefficients (Afshari et al., 2023). The limited information approach covers Ordinary Least Squares (LS), Two-Step Least Squares (TLS), Weighted Ordinary Least Squares (WLS), and Weighted Two-Step Least Squares (WTLS) (Liang et al., 2023). The full information approach involves Three-Step Least Squares (TLS), Generalized Methods of Moments (GMM), Seemingly Unrelated Regressions (SUR), and Full Information Maximum Likelihood (FML) (Nodehi et al., 2022; Taghvaee et al., 2017, 2024; Tatar et al., 2024; Petukhov et al., 2014).

In addition, the estimation process continues with the following Granger causality method. The results can reveal both the direction and significance of the causal relationships as well as their long-run relationships in Model 2. This causality method is represented by Model 3.

$$\Delta LE_{it} = C_t + \sum_{l=1}^{p} \alpha_{1l}\Delta LE_{jt-l} + \sum_{l=1}^{p} \alpha_{2l}\Delta CO^{-1}{}_{jt} + \sum_{l=1}^{p} \alpha_{3l}\Delta GDP_{jt} + \varepsilon_{1t}$$

$$\Delta CO^{-1}{}_{it} = C_t + \sum_{l=1}^{p} \beta_{1l}\Delta LE_{jt-l} + \sum_{l=1}^{p} \beta_{2l}\Delta CO^{-1}{}_{jt} + \sum_{l=1}^{p} \beta_{3l}\Delta GDP_{jt} + \varepsilon_{1t}$$

$$\Delta GDP_{it} = C_t + \sum_{l=1}^{p} \theta_{1l}\Delta LE_{jt-l} + \sum_{l=1}^{p} \theta_{2l}\Delta CO^{-1}{}_{jt} + \sum_{l=1}^{p} \theta_{3l}\Delta GDP_{jt} + \varepsilon_{1t} \quad (3)$$

where l signifies lag and p indicates optimal lag.

This method is appropriate for the sustainability measurement since it can involve the comprehensive concepts of sustainability pillars while estimating their interconnections as the spillovers (Afshari et al., 2023). It can encompass both aggregated and disaggregated approach to the analysis of sustainable development perspectives including weak, strong, and integrated sustainability. This technique examines the sustainable development perspectives as a whole while measuring the spillovers of their pillars as a decomposed analysis (Mishra et al., 2023). This approach has been employed by different studies on the investigation of sustainable development in various regions and different time periods. By adding the logarithmic form of the variables, this model allows the estimation of sustainability elasticities (Bautista-Puig et al., 2023). In this way, it estimates the elasticities of each sustainability pillar to offer numerical and statistical insight into the spillover effects of sustainability while providing a comprehensive and conceptual understanding of the sustainable development (Alaimo et al., 2021; Mishra et al., 2023; Yamaguchi et al., 2023).

If the coefficients are positive and statistically significant, the spillovers are synergic. Such estimate confirms the integrated sustainability perspective, supporting globalization and flow-based governance in Indonesia, China, and the US. However, the spillovers are trade-off if the coefficients are negative and statistically significant, rejecting integrated sustainability and accepting de-globalization and local-based governance (Behera & Pozhamkandath Karthiayani, 2022; Boillat et al., 2018; Cotta et al., 2022). Furthermore, the results can confirm the strong perspective of sustainability if the estimated coefficients of pillar of environment are larger than the coefficients of the aspects of economy and social. If the estimations show a symmetric and equal pattern of spillovers among the three pillars, the weak sustainability perspective is accepted in Indonesia, China, and the US (Mamipour et al., 2019; Yousaf et al., 2023).

4. Data

In this study, life expectancy, inversed CO2 emissions in per capita, and GDP per capita are proxies of social, environmental, and economic development, respectively. Life expectancy, CO2 emissions, and GDP are measured in year, metric ton, and constant 2015 US Dollar, respectively. They are extracted from the World Development Indicators, World Bank for a sample period within 1974 and 2020.

Fig. 4 displays the trends of life expectancy across the US, China, and Indonesia. Regarding the figure, the life expectancy similarly increases in all the sample countries, despite some differences. The US overtakes China and Indonesia throughout the period but China, except for the last year where the US and China indicate the same value. In addition, Indonesia shows the lowest values but it continuously increases within the span. Therefore, all the countries commonly have an upward trend of life expectancy.

Fig. 5 illustrates the CO2 emissions per capita in the US, China, ad Indonesia during the last five decades. Based on the figure, although the US and Indonesia hold the highest and lowest values of emissions during the span, respectively, they indicate convergent trends to become closer to each other.

Fig. 6 demonstrates the GDP per capita of the US, China, and Indonesia. All the three countries commonly indicate an increasing trend despite their different values. The US holds the greatest GDP per capita within sample period. Although China indicates the lowest values in the first half of the period, it succeeds Indonesia at the beginning of the 2000 s to become closer to the US. Therefore, all the trends have similarly an upward direction.

5. Result

The estimations indicate significant spillover effects among the sustainability aspects of economy, environment, social and from the US and China to Indonesia within 1974–2020. Tables 2 and 3 represent the estimates of the sustainability elasticities among the three sample countries.

According to Table 2, the coefficients of life expectancy and GDP in the US are 0.9879 and 0.0608 in the equation of life expectancy in Indonesia, which are synergistic and significant at 1 % level. This estimate shows that the sustainability elasticities of social development in Indonesia are + 98 % and + 6 corresponding to the social and economic dimensions in the US, respectively. Moreover, the coefficients of life expectancy and GDP in the US are 0.9586 and 0.1280 in the equation of inversed CO2 emissions in Indonesia, which are synergistic and significant at 1 % level. In contrast, the inversed CO2 emissions shows a coefficient equals −0.0549 and statistically significant at 5 % level. Such estimate reveals that sustainability elasticities of environmental development in Indonesia are + 95 %, −5%, and + 12 % corresponding to the aspects of economy, environment, and social in the US, respectively. Furthermore, the coefficients of life expectancy and GDP in the US are 0.9491 and 0.1367 in the equation of GDP in Indonesia. They represent synergistic effects which are significant at 1 % level. In contrast, the inversed CO2 emissions coefficient equals to −0.0607. It represents a negative impact which is significant at 1 % level. The estimate indicates that sustainability elasticities of economic development in Indonesia are + 94 %, −6%, and + 13 % corresponding, respectively, to the aspects of social, environment, and economy in the US.

Regarding Table 3, coefficients of life expectancy and GDP in China are 1.1821 and 0.2172 in the equation of life expectancy in Indonesia, which are synergistic and significant at 1 % level. In contrast, the inversed CO2 emissions coefficient is equal to −0.3950. This estimate is significant at 1 % level confirming negative impacts. Such finding indicates that the sustainability elasticities of social development in Indonesia are + 118 %, −39 %, and + 21 % corresponding to the aspects of social, environment, and economy in China, respectively. Moreover, the coefficients of life expectancy and GDP in China are 0.6248 and 0.4200 in the equation of inversed CO2 emissions in Indonesia, which are synergistic and significant at 1 % level. Such estimate shows that the

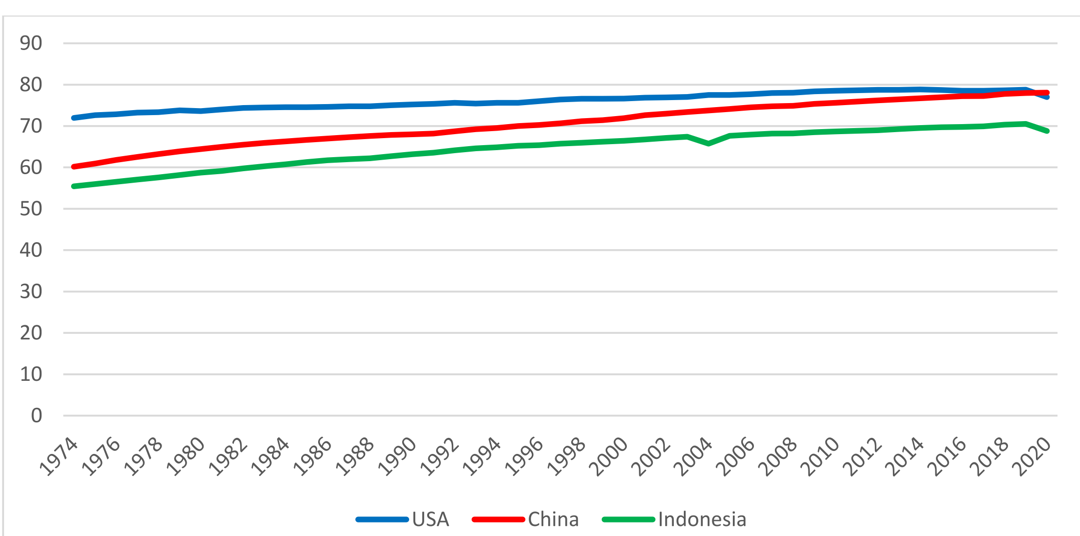

Fig. 4. Life expectancy in the USA, China, and Indonesia within 1974 and 2020 (measured in year)
Source: World Bank, 2024.

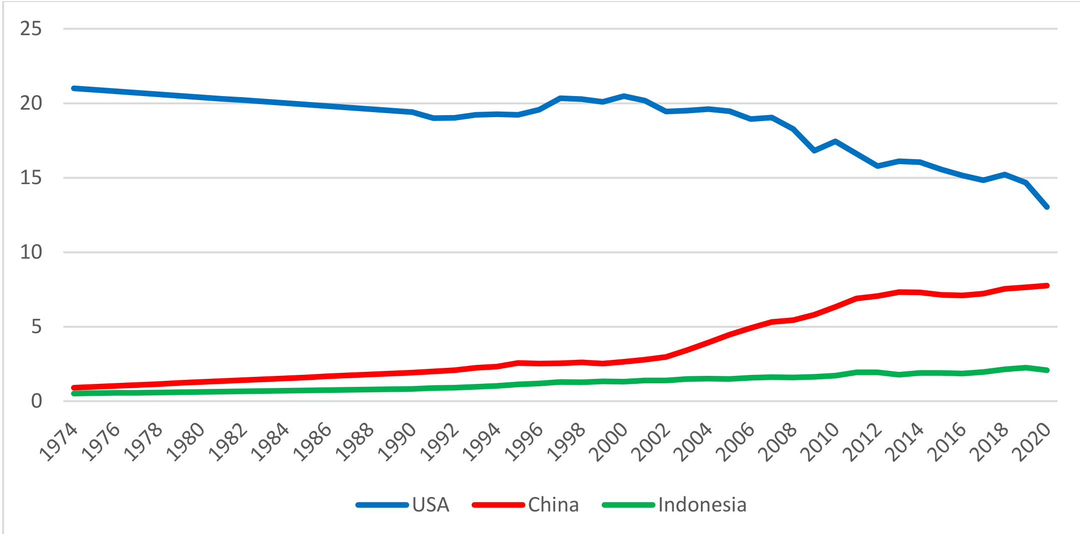

Fig. 5. Natural logarithm of carbon dioxide emissions per capita in the USA, China, and Indonesia within 1974 and 2020 (measured in metric ton)
Source: World Bank, 2024.

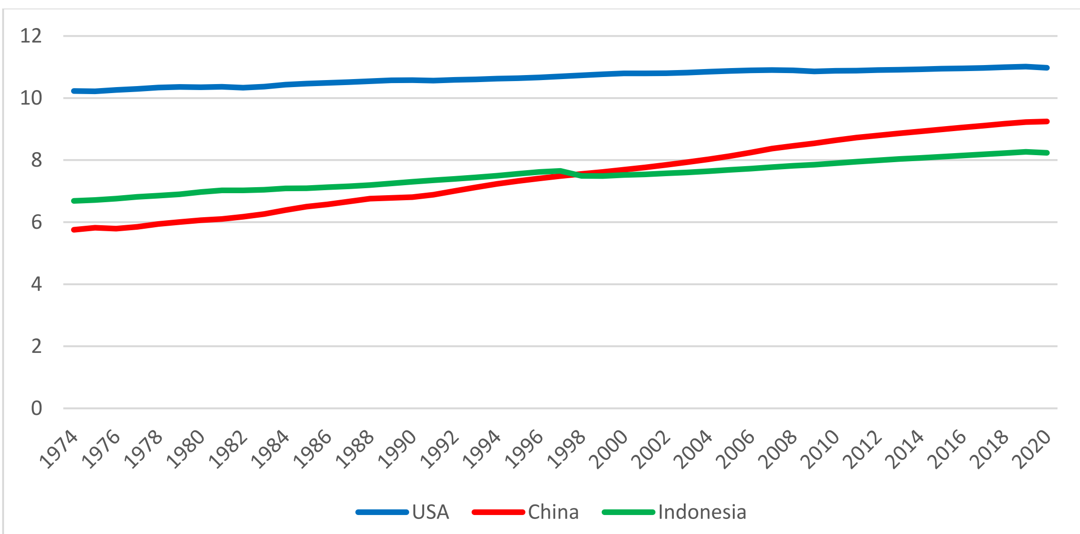

Fig. 6. GDP per capita in the USA, China, and Indonesia within 1974 and 2020 (measured in constant 2015 US Dollar)
Source: World Bank, 2024.

sustainability elasticities of environmental development in Indonesia are + 62 % and + 42 % corresponding to the aspects of social and economy in China, respectively. In addition, the coefficients of life expectancy and GDP in China are 0.6032 and 0.2984 in the equation of GDP in Indonesia, which are synergistic and significant at 1 % level. Such estimation denotes that the sustainability elasticities of economic aspect in Indonesia are + 60 % and + 29 % corresponding to the aspects of social and economy in China, respectively.

Therefore, the estimated coefficients reveal significant relationships between the sustainability pillars of Indonesia, China, and the US, which are mainly positive and synergistic, except for some exceptions. These results are mostly repeated in the different estimation methods, which confirm their robustness, stability, and validity. To provide a more understandable image of the results, this research graphically translates the results of Tables 2 and 3 in the following figures.

Fig. 7 illustrates the positive and considerable interactions of social pillars of sustainability between Indonesia, the US, and China, which supports the integrated sustainability. This output is for the substantial synergistic spillovers among the humanistic elements such as education, labor-force, health, culture, and policy. In addition, the economic pillars of China and the US have a synergistic impact on the social pillar of sustainability in Indonesia. A reason for this finding is that economic development in the two countries provide more appropriate environments for working, education, cultural activities, and medical services and facilities in Indonesia through greater supportive transfer of finance, trade, and technology. However, the environmental development in China shows a trade-off relationship with social development in Indonesia. An explanation for this result is that the progressive contribution of Chinese industries to the advanced, green, and efficient technologies, which improve the environment, can attract the skillful workers and human capital of Indonesia, leading to degradation in its social development. Furthermore, the map of these elasticities indicates a symmetric nature of sustainability spillovers among Indonesia, China, and the US.

Fig. 8 demonstrates the spillovers among sustainability dimensions in the US and China on the environmental development in Indonesia.

Table 2
Estimated sustainability elasticities and causality relationships among sustainability aspects of social, environment, and economic between Indonesia and the US.

Indonesia ⇐US	Limited information approach (single equation)				Full information approach (single equation)				Granger
	OLS	WOLS	2SLS	WSLS	3SLS	SUR	GMM	FIML	Causality
LE equation $_{Indonesia}$									Optimal lag = 5
C	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	0.0111	–-
	(0.66)	(0.65)	(0.65)	(0.65)	(0.65)	(0.65)	(0.76)	(0.96)	
LE $_{US}$	0.9879***	0.9879***	0.9879***	0.9879***	0.9879***	0.9879***	0.9879***	0.9879*	$LE \Longrightarrow LE$(0.93)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.05)	
CO^{-1} $_{US}$	−0.0092	−0.0092	−0.0092	−0.0092	−0.0092	−0.0092	−0.0092	−0.0092	$CO^{-1} \Longrightarrow LE$(0.62)
	(0.26)	(0.24)	(0.24)	(0.24)	(0.24)	(0.24)	(0.00)	(0.98)	
GDP $_{US}$	0.0608***	0.0608***	0.0608***	0.0608***	0.0608***	0.0608***	0.0608***	0.0608	$GDP \Longrightarrow LE$(0.84)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.83)	
CO^{-1} equation $_{Indonesia}$									
C	−0.5828***	−0.5828***	−0.5828***	−0.5828***	−0.5828***	−0.5828***	−0.5828***	−0.5828	–-
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.30)	
LE $_{US}$	0.9586***	0.9586***	0.9586***	0.9586***	0.9586***	0.9586***	0.9586***	0.9586***	$LE \Longrightarrow CO^{-1}$(0.96)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
CO^{-1} $_{US}$	−0.0549**	−0.0549**	−0.0549**	−0.0549**	−0.0549**	−0.0549**	−0.0549**	−0.0549	$CO^{-1} \Longrightarrow CO^{-1}$(0.58)
	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.96)	
GDP $_{US}$	0.1280***	0.1280***	0.1280***	0.1280***	0.1280***	0.1280***	0.1280***	0.1280	$GDP \Longrightarrow CO^{-1}$(0.92)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.16)	
GDP equation $_{Indonesia}$									
C	−0.6147***	−0.6147***	−0.6147***	−0.6147***	−0.6147***	−0.6147**	−0.6147***	−0.6147	–-
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.20)	
LE $_{US}$	0.9491***	0.9491	0.9491***	0.9491***	0.9491***	0.9491***	0.9491***	0.9491*	$LE \Longrightarrow GDP^{**}$
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.07)	(0.03)
CO^{-1} $_{US}$	−0.0607***	−0.0607 (0.00)	−0.0607***	−0.0607***	−0.0607***	−0.0607***	−0.0607***	−0.0607	$CO^{-1} \Longrightarrow GDP$(0.11)
	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.93)	
GDP $_{US}$	0.1367***	0.1367***	0.1367***	0.1367***	0.1367***	0.1367***	0.1367***	0.1367	$GDP \Longrightarrow GDP^{***}$
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.70)	(0.00)

Table 3
Estimated sustainability elasticities and causality relationships among sustainability aspects of social, environment, and economic between Indonesia and the China.

Indonesia ⇐ China	Limited information approach (single equation)				Full information approach (single equation)				Granger
	OLS	WOLS	2SLS	WSLS	3SLS	SUR	GMM	FIML	Causality
LE equation $_{Indonesia}$									Optimal lag = 5
C	0.0603***	0.0603***	0.0603***	0.0603***	0.0603***	0.0603***	0.0603***	0.0603	–-
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.49)	
LE $_{China}$	1.1821***	1.1821***	1.1821***	1.1821***	1.1821***	1.1821***	1.1821***	1.1821***	$LE \Longrightarrow LE$(0.36)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
CO^{-1} $_{China}$	−0.3950***	−0.3950	−0.3950***	−0.3950***	−0.3950***	−0.3950***	−0.3950***	−0.3950**	$CO^{-1} \Longrightarrow LE$(0.22)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)	
GDP $_{China}$	0.2172***	0.2172***	0.2172***	0.2172***	0.2172***	0.2172***	0.2172***	0.2172	$GDP \Longrightarrow LE$(0.65)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.12)	
CO^{-1} equation $_{Indonesia}$									
C	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	0.0058	–-
	(0.86)	(0.85)	(0.86)	(0.85)	(0.85)	(0.85)	(0.87)	(0.94)	
LE $_{China}$	0.6248***	0.6248***	0.6248***	0.6248***	0.6248***	0.6248***	0.6248***	0.6248	$LE \Longrightarrow CO^{-1}$(0.15)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.29)	
CO^{-1} $_{China}$	−0.0437	−0.0437	−0.0437	−0.0437	−0.0437	−0.0437	−0.0437	−0.0437	$CO^{-1} \Longrightarrow CO^{-1}$(0.31)
	(0.70)	(0.69)	(0.70)	(0.69)	(0.69)	(0.69)	(0.85)	(0.85)	
GDP $_{China}$	0.4200***	0.4200***	0.4200***	0.4200***	0.4200***	0.4200***	0.4200***	0.4200	$GDP \Longrightarrow CO^{-1}$(0.51)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.20)	
GDP equation $_{Indonesia}$									
C	−0.1050***	−0.1050*	−0.1050***	−0.1050***	−0.1050***	−0.1050***	−0.1050**	−0.1050	–-
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.51)	
LE $_{China}$	0.6032***	0.6032***	0.6032***	0.6032***	0.6032***	0.6032***	0.6032***	0.6032**	$LE \Longrightarrow GDP$(0.11)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	
CO^{-1} $_{China}$	0.0953	0.0953	0.0953	0.0953	0.0953	0.0953	0.0953	0.0953	$CO^{-1} \Longrightarrow GDP$(0.97)
	(0.46)	(0.44)	(0.46)	(0.46)	(0.44)	(0.44)	(0.50)	(0.78)	
GDP $_{China}$	0.2984***	0.2984***	0.2984***	0.2984***	0.2984***	0.2984***	0.2984***	0.2984*	$GDP \Longrightarrow GDP$(0.29)
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.06)	

Regarding this figure, the life expectancy or social pillar of China increases the CO2 emissions in Indonesia, damaging its environmental development. The inference of this result is that if life expectancy in China as a highly-populated country increases, the world demand for different goods and services increases, which heightens their price level and induces the supply side. This supply stimulation further intensifies the exploitation of resources and emissions of greenhouses gases, damaging the environmental development in Indonesia. In contrast, the social development in the US improves the environmental development in Indonesia. This finding can be explained by the analysis that strong

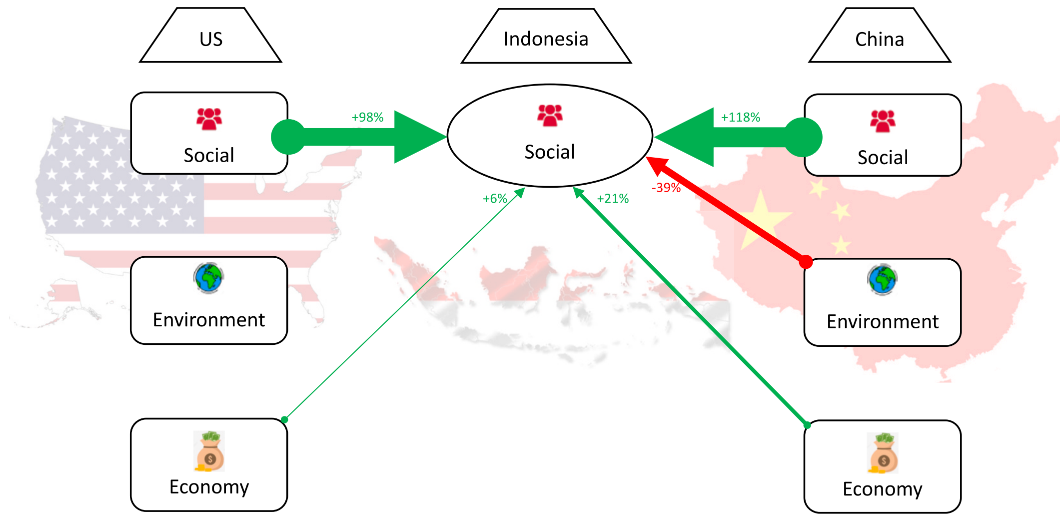

Fig. 7. Estimated sustainability spillovers from the US and China to the social development in Indonesia Source: Authors' estimations.

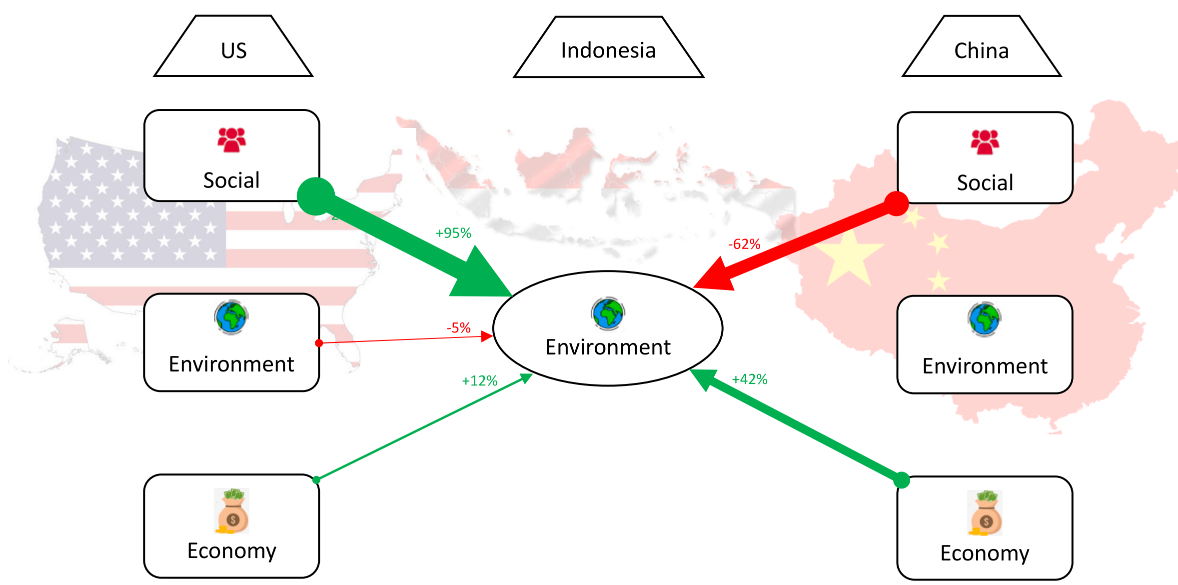

Fig. 8. Estimated sustainability spillovers from the US and China to the environmental development in Indonesia Source: Authors' estimations.

educational plans for green and environmentally friendly technologies and projects in the US have internationally synergistic impacts on the environmental development in Indonesia. In this way, the social development in China and the US have conflicting impacts, i.e. trade-off and synergistic,

However, the economic development in the US and China flows synergistic spillovers to the environmental pillar of Indonesia. A reason for this outcome is that the export products of the US and China have high environmental standards including green and environmentally friendly technologies for Indonesia. In other words, these countries locate on the descending part of the Environmental Kuznets Curve, benefiting from the highly advanced and efficient technologies with lower energy consumption and polluting emissions. Thus, economic pillar of the US and China improve the environment in Indonesia.

Fig. 9 displays that economic pillar of Indonesia receives synergistic spillovers from the social and economic development of the US and China. According to this figure, the life expectancy in China and the US improves GDP in the US and China by providing more workers with higher productivity. An explanation of this estimation is the productivity theory which highlights the constructive role of transferring educational supports, human capital, and political collaborations. In addition, economic development in China and the US improves the economic development in Indonesia, implying the inducing impacts of international growth and trade on the domestic economic growth of Indonesia. Furthermore, the sustainability spillovers of the US and China represent a symmetric effect on the economic development in Indonesia.

Fig. 10 represents the estimated spillovers using causal relationships of the sustainable development pillars. The results of causality examination affirm the symmetric flows of sustainability spillovers among Indonesia, China and the US. This finding confirms that Indonesia equally benefits from the interconnection with the western and eastern economic powers, i.e., the US and China, indicating its balanced relationships with the global polars and regions.

6. Discussion

This study finds that the pillars of sustainability have considerable and synergistic impacts on one another among Indonesia, China, and US, supporting the idea of spillovers and integrated sustainability. More accurately, the result means that development of social, environment,

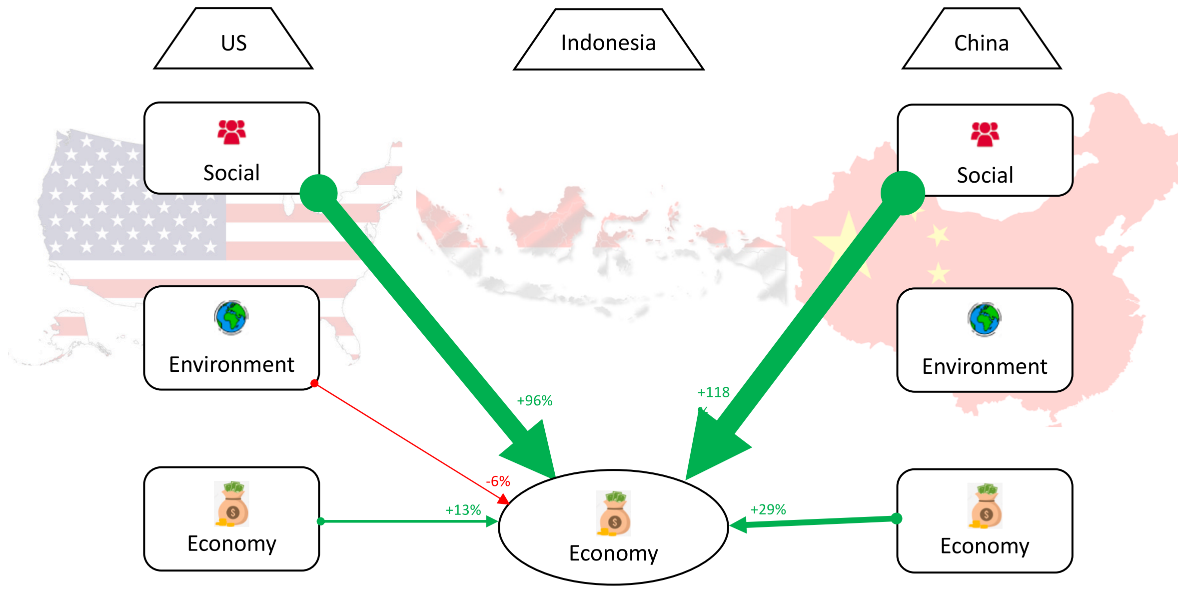

Fig. 9. Estimated sustainability spillovers from the US and China to the economic development in Indonesia Source: Authors' estimations.

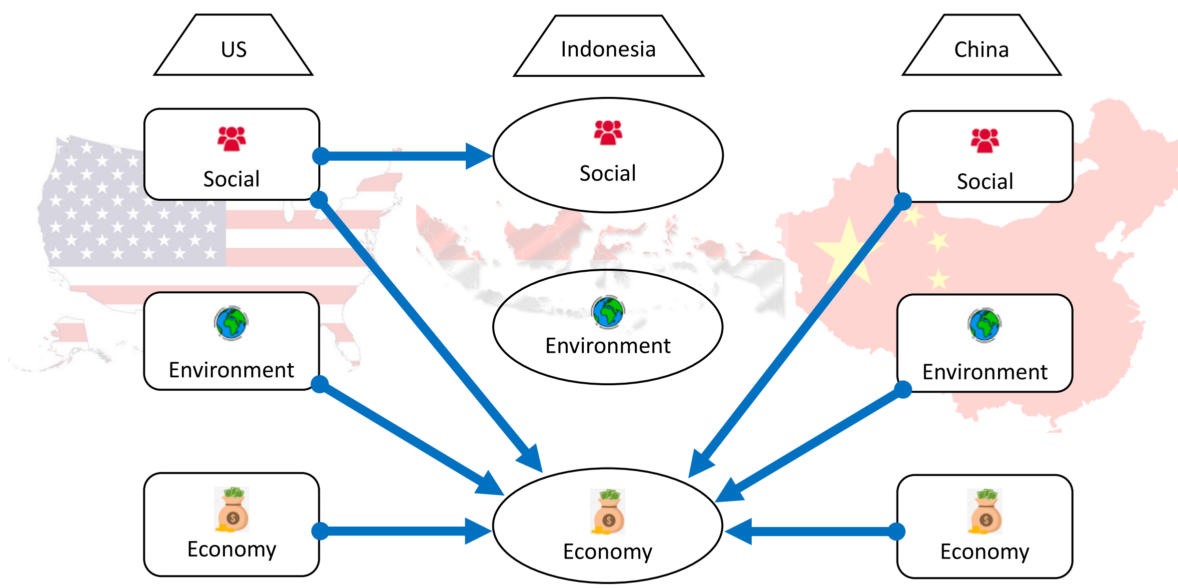

Fig. 10. Estimated flows of sustainability spillovers from China and the US to the sustainability pillars in Indonesia using causality relationships Source: Authors' estimations.

and economy in China and US substantially enhance the sustainability enhancement across China and US. A reason for this finding is the substantial interconnections among different parts and elements of a society, economy, and country. This interconnection establishes a network of spillovers flowing between all the features of sustainable development at national, regional, and international levels. This result affirms that sustainable development has regionally synergistic spillover effects, which aligns with Afshari et al., (2023) and Mohamad Taghvaee et al., (2022). Based on this finding, this research accepts spillovers as the 4th dimension of sustainability like the classical dimensions of environment, economy, and social. Hence, it promotes integrated sustainability attitude. According to this result, this study promotes flow-based governance, peaceful relationships, and globalization while rejecting local-based governance and de-globalization, requiring the development and promotion of international organization and agreements.

Moreover, the map of sustainable development spillovers delineates symmetric flows from the US and China towards sustainability in Indonesia. Such a symmetric design refuses the strong sustainability perspective which attaches a greatest significance to environmental pillars of sustainability, in comparison with the economic and social pillars. This finding highlights the importance of establishing and maintaining a balanced connection with the world large economies such as China and the US. In other world, the improvement of sustainable development requires a peaceful and harmonized interconnection with various regions of the globe by following a multilateral governance instead of following a unilateral hegemony. This approach needs the global promotion of peace and partnership by mitigating tensions among countries.

The findings of this research highlight the role of spillover effects in the context of sustainable development. One of the main reasons for this finding is the importance of establishing harmonization among different sectors and subsectors of an economy, various elements of the society, and diverse feature of the environment. This network of interconnections can be explained by the necessity of a balanced pattern for the progress of developmental plans. Accordingly, an effective strategy for the enhancement of sustainable development requires a balanced and harmonized structure, rather than focusing on some specific areas for development. Another explanation for the results is the essential role of international relationships through trade, political collaboration, and diplomatic connections.

7. Conclusion

This study designs the sustainability spillovers among Indonesia, China, and the US to check the integrated sustainability. For this purpose, it measures elasticities of sustainable development corresponding to social, environment, and economy within 1974–2020 using the SEY model as an econometric approach. The estimation indicates that the elasticities are mainly high and synergic, meaning that the sustainability dimensions mainly represent substantial and synergistic spillovers within the studied countries. This result interprets the spillovers like the 4th sustainability dimension, which supports the perspective of integrated sustainability, while defying strong and weak perspectives of sustainability. Moreover, the findings denote that spillovers have a symmetric distribution between the US and China, attaching equal importance to the relationships with the western and eastern economies of the world.

The theoretical and policy implications of the synergistic and symmetric spillovers from the US and China towards Indonesia are as follows. From a national outlook, Indonesia should consider a comprehensive strategy for its developmental progress that includes all the social, environmental, and economic aspects of sustainable development. It should accelerate the economic growth by investing in infrastructural projects while improving the social development via promotion of equal access to education, health, and job opportunities. Simultaneously, it should reduce the environmental pollution through encouraging green technologies, adopting stringent environmental regulations, and efficient waste management. This broad view of economic development smooths the way for social and environmental development by providing the required resources and stability for sustainable practices and inclusive developmental plans.

Regarding an international angle, governments, especially in Indonesia, should establish and maintain peaceful and strong relationships with other countries, particularly the large economies of the west and the east like the US and China. In this policy-making, they should follow a balanced relationship with the two economic polars to be benefited from the synergistic spillovers of both. To achieve these goals, they should reduce tensions in their relationships with other countries, join international organizations, sign global agreements, and follow the world regulations. From the theoretical implication viewpoint, the finding of this research adds the spillovers of sustainability as another aspect of sustainability to classical dimensions of economy, environment, and social. This addition implies that the spillovers play the greatest role in the sustainability, affirming the perspective integrated sustainability.

The theoretical implication of the findings is that the high elasticity of each sustainable development pillar corresponding to changes in the other pillars. This finding implies that spillover effects have fundamental impacts in the context of sustainable development. In other words, this result highlights the key role of spillover effects as the fourth pillar of sustainable development, which is consistent with the integrated sustainability perspective. However, they are inconsistent with the strong sustainability perspective due to rejecting the dominant role of environmental pillar in sustainable development. They also refuse the weak sustainability perspective due to the asymmetric distribution of the spillovers which implies heterogeneous and unbalanced effects of sustainable development pillars. Therefore, the findings affirm the integrated sustainability perspective by introducing the spillovers as the fourth pillar of sustainability in the context of Indonesia while rejecting the strong and weak sustainability perspectives.

This research involved limitations regarding the selected sample, employed method, and analyzed variables. The studied sample includes only three single countries, Indonesia, China, and the US, which provide a partial coverage of western and eastern economic powers. In addition, the applied method and its specified regression, i.e., the SEY model, holds only three broad dimensions, i.e., social, environment, and economy, ignoring an effectively disaggregated analysis. For example, social development goes beyond only one variable, which is life expectancy in this research. Thus, this high level of aggregation cannot reveal relationships among decomposed elements of sustainable development. Correspondingly, the variables have incomplete capacity to bring all the aspects of each sustainable development, lacking a highly comprehensive involvement of all the aspects underlying a pillar of sustainable development. For instance, CO_2 emissions can only indicate air pollution, disregarding the other features of the environmental conditions such as water quality, waste management, and deforestation.

To develop this research, other researchers can contribute to removal of this study's limitations by enriching the study sample, utilized method, and investigated variables. They can expand the sample to a larger group of countries such as developed and developing countries to broaden the range of economies effective in the spatial spillovers of sustainability at global and regional levels. Furthermore, they can use alternative methods with the capability of involving further details of sustainability aspects, rather only social, environment, and economic dimensions. In this way, a more decomposed analysis can reveal more details about the spillover effects of sustainable development among countries. Alternatively, future studies can add more variables to the analysis to expand its decomposition level so as to measure the spillovers of various elements of sustainable development. By involving these considerations, they can reveal a more comprehensive map of sustainability spillovers while involving more details about the sustainability spillovers via further decomposition of the sustainable development pillars.

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CRediT authorship contribution statement

Jian Li: Data curation, Supervision, Validation, Writing – review & editing. **Vahid Mohamad Taghvaee:** Writing – review & editing, Validation, Software, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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