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# The impact of economic development on environmental sustainability: evidence from the Asian region

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**Abstract**
This study investigates the relationship between economic development and environmental sustainability (ES) of 42 Asian countries from 2000 to 2017. We propose an ordinary least square (OLS) and fully modified ordinary least square (FMOLS) model to estimate the result. The OLS estimators of the balanced panel data on the aggregate sample and six subgroups of ecological area evidence some key findings. These are: (i) There is a significant positive linear relationship between economic growth (EG) and ecological footprint (EF); however, the relationship between EG and biocapacity (BC) is nonlinear. (ii) Among the subgroups that build up the land, samples depict a linear relationship with EG in EF and BC cases. (iii) Other than carbon-absorbing land and grazing land in the subgroup of EF, all other subgroups against environmental sustainability parameters show a nonlinear relationship with EG. (iv) The inverted U-shape curve is evident in Asian countries in explaining the relationship between EG and ES, and the impact of development indicator (GDP) on ecological subgroups is heterogeneous. The cointegration tests of the FMOLS model suggest the existence of a long-term relationship between the variables. Finally, the empirical observations show a growing trend of ecological deficit in Asia and advocate rapid policy development for environment-friendly economic development.

**Keywords** Environmental sustainability · Ecological footprint · Biocapacity · Ordinary least square

## 1 Introduction

The modern world is blessed with high technology, industrialization, and urbanization and enjoys more benefits in the form of a higher lifestyle, upper-income level than the people of the early era. Modernization in the form of urbanization, industrialization, and technological advancement makes life easy and brings economic development and a superior lifestyle. However, with the growth of modernization and economic development, concern regarding environmental protection becomes a vital issue in every corner of the world.

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Therefore, every interest group of the globe needs to be concerned about this inevitable issue of environmental sustainability (ES) for the existence of the world's ecological balance. The concept of ES is not a new one. Pearce and Vanegas (2002) opine that the idea of ES emerged from the theory of appropriate technology and environmental awareness of the 1970s. Although there is no consensus regarding the definition of ES, the prime concept refers to the protection of the environment from the creation of pollution, degradation of energy and renewable resources, deterioration of natural resources, etc. which is also affected by several factors (Ahmad et al., 2021; Syed & Tollamadugu, 2019). Changes in European environmental policy (Jordan, 1999), transnational political agreements regarding the environment, and emphasis on environmental protection by the supranational like United Nations (Cichowski, 1998) depict the environmental concern both nationally and globally.

Continuous changes in climate such as global warming, melting ice, rising sea level draw attention and tension of the environmentalist and scientists for the world's survival. In the last few decades, rapid change of environment (Ren et al., 2006) raises a question yet to find the answer. Are the people conscious about ES besides economic development? This question is grounded due to continuous environmental degradation and global warming despite having policy dialogs and regulations at national and international levels. However, the world is witnessing economic progress that makes the nations but yet to improve environmental protection to a large extent. This question fuels us to delve into the impact of economic development in ES, taking 42 Asian countries for 2000–2017 as our sample, as this region is the largest and most populated region in the world.

There is a growing body of literature that recognizes economic development and environmental sustainability (Cialani, 2007; Ibrahim & Alola, 2020; Pérez-Gladish et al., 2020; Wei et al., 2017). Researchers from different parts come forward with diversified outcomes (Aydin et al., 2019; Castellani & Sala, 2012; Leonidou et al., 2015; Mukhtar et al., 2021) and examine the relationship between economic development and ES. However, research on specific Asian countries examining the impact of economic growth (EG) with multiple subgroups of EF is scarce in the literature and their long-term effect on each country level is still unknown. This vacuum motivated us to investigate the mentioned above study. To examine the impact, this study addresses economic development through per capita GDP, and per capita ecological footprint (EF), per capita biocapacity (BC) to refer to ES parameters. Notably, this study is designed to find three basic questions: (1) Does per capita GDP affect per capita EF in Asian Region? (2) Is per capita BC increasing with per capita GDP? (3) Does ES exist in the Asian region?

This study makes a unique contribution to the literature of environmental sustainability in the following aspect. Firstly, the study evidences the impact of economic development on ES for the studied period using a stochastic ordinary least square method. Additionally, this paper has used six subgroups of EF to make this study more dynamic: cropland, fishing grounds, grazing land, carbon-absorbing land, forest products, and buildup land. The findings of the study evidence the effect of per capita GDP on the subgroup of per capita EF individually as well. For different subgroups of per capita EF, this study observes a different relationship between per capita GDP and a subgroup of EF per capita for the 42 Asian countries from 2000 to 2017. Secondly, a fully modified ordinary least square (FMOLS) model has been proposed to investigate the long-term cointegration between the variables and their single country effects. The FMOLS results show that the foreign direct investment (FDI), the unemployment rate (UR), BC, and carbon dioxide ($CO_2$) emissions affect the EF in the sample of countries analyzed. Thirdly, this study also delves into the relationship between per capita BC and per capita GDP, making the research question more potential. The result also evidenced the nonlinear relationship between economic development and ES indicators. Finally, based on the findings, appropriate policy guidelines for environmental protection and environmental sustainability have been suggested so that the government and policymakers will develop suitable economic development objectives and strategies.

Our study is organized as follows: Sect. 2 analyzes the existing studies on economic development and environmental sustainability. Section 3 describes the origins of data and variables. Section 4 outlines the research methods, and Sect. 5 portrays the results and discussion. The final section depicts the concluding remarks.

## 2 Literature review

For the convenience of discussion and readership, we divide the covered literature into four sections such as the indicators that measure environmental damage and impacts, environmental pressure and economic development, literature regarding Environmental Kuznets Curve hypothesis, and EF and economic development.

### 2.1 Indicators measure environmental damage and impacts

The literature depicting the environmental quality indicator is diversified. Cialani (2007) mentions seven ecological indicators: atmosphere, water, biota, land, waste, natural economic resources, and miscellaneous. Again, Montero et al. (2010) address six indicators to measure the environmental quality, i.e., water, ambient sulfur oxides ($SO_2$), sanitation, dissolved oxygen, suspended particulate matter (SPM), and fecal coliforms in rivers. From the literature, we cluster all indicators mainly in four categories: first, atmospheric indicators such as $CO_2$ emissions, $SO_2$ emissions, nitrogen dioxide ($NO_2$) emissions, and methane ($CH_4$); Second, land indicators such as cropland, use of fertilizer, use of pesticides, and degradation of land; Third, freshwater indicators such as treatment of wastewater; and Fourth, ocean indicators such as status of ocean species, index of marine trophic, and quality of ocean water. Among all of the indicators, atmospheric indicators are mostly used (Sarkodie & Strezov, 2019).

Nowadays, EF has become familiar as an environmental indicator that can measure the impacts of damage to the environment. Both the activity of economics and the output of this economic activity, known as the use of renewable resources, are measured by EF (Caviglia-Harris et al., 2009). Using EF to measure ES is that it denotes the capacity of the earth by which demand of humans and activities of humans that worsen the capacity of the earth (Wackernagel & Rees, 1998). In other words, we can say EF is a tool by which ecological demand and supply can be measured in an area (Wackernagel et al., 2005). The average global productivity balancing between the desire of EF and supply of EF is better explained by the term 'bio-productive capacity' and can be determined through global hectares (Hammond & Seth, 2013).

It's known that ES is decreasing with excessive use of biocapacity compared with EF, and this situation is called an ecological deficit. Recent studies are pointing to many reasons behind this situation. Senbel et al. (2003) opine that increasing volume of economic activities and consumptions inversely affects ecological productivity and long-term sustainability. The economic scale of production adversely affects the environment, whereas technological improvement in the production process reduces environmental pollution

(Hao et al., 2020). Different studies support and measure EF to determine ES. For instance, Aydin et al. (2019) preach that EF is a useful tool to measure ecological productivity, including land and water resources of nature. A study by Aydin et al. (2019) examines the impact of EF by grouping six types of land and observes the heterogeneous effect on different lands. Uses of the EF method spread out cities, regions, nations to the whole globe (Hurley et al., 2007). EF was also found useful in measuring ecological banks in urban areas (Holden, 2004) and even examining human activities like work by traveling (Muñiz & Galindo, 2005).

### 2.2 Environmental pressure and economic development

There is a long-standing debate regarding the relationship between environmental pressure and economic development. Some arguments support environmental degradation (ED) with economic progress, whereas others advocate economic development for improved quality environment and sustainability. The literature like Andreoni and Levinson (2001), Dinda (2004), Schandl et al. (2016), Wang et al. (2021) among others supports the ED with the increase in economic activities. They argue that atmospheric pressure like air pollution increases with a higher level of consumption and production. However, they also support that countries with high income are combating better ways than low-income countries in balancing pollution and consumption. Environmental pressure is also affected by energy consumption. The empirical investigation of Deng et al. (2021) indicate the positive association of social and economic development in the environment in the form of energy consumption.

On the contrary, some literature supports a positive association between economic development and environmental improvement. Arrow et al. (1995) empirically show the improved environmental quality with the increase in the per capita income of a nation. A similar finding was also observed in the study of Shafik (1994). The author pronounces those different classes of environmental improvement, like access to clean water, and sanitation increase with economic development.

Again, few studies evidenced the mixed result and opine that economic development does not possess a linear relationship with ED. Panayotou (1997) reports that the relationship of EG is not linear; up to a certain level, faster EG inversely affects the environment, but the better policy can play an active role in environment-friendly economic growth. Supporting the nonlinear relationship, Wang and Li (2019) and Fodha and Zaghdoud (2010) also have shown an inverted U-shaped curve between $CO_2$ and EG and there is not a one-way relationship between them. The findings of the literature show the mixed result advocate the Environmental Kuznets Curve (EKC) Hypothesis to explain the relationship between EG and environmental pressure. EKC was also evident in the study of Hao et al. (2021). The authors have shown a nonlinear relationship between environmental degradation with the increase in economic growth. Initially, environmental degradation increases with the increase in economic growth and then decreases.

In the discussion of the literature, it is clear that economic development significantly affects the environment. However, the impact of the environment also has a significant influence on economic performance addressed in the literature. Examining the relationship between hard environmental regulation and export volume, Shi and Xu (2018) observe that the probability of export volume reduces in pollution-intensive industries in China. Leonidou et al. (2015) opine that green and environment-friendly business strategies positively affect product differentiation and export expansion. Again, Au and Henderson (2006) point out the association between urban agglomeration and the EG of a country. The authors empirically show the positive association between environmental change and EG.

### 2.3 Literature regarding the environmental Kuznets curve (EKC) hypothesis

The pioneering work of Kuznets (1955) explains the inverted-U relationship between two variables. Subsequently, a nonlinear relationship is also used in describing the systematic relationship between environmental quality and income known as Environmental Kuznets Curve (Dinda, 2004). Primarily EKS suggests how the environment changes with the change of the large human community. However, EKS hypothesizes an inverted U-shape relationship in explaining the relationship between environmental pollution and income per capita (Dinda, 2004). Many research work like Jayanthakumaran et al. (2012), Aye and Edoja (2017), Akbostancı et al. (2009), among others, use EKC to illustrate the relationship between environmental indicators and economic development. The literature uses EKC not necessarily work on the same indicator. For example, Llorca and Meunié (2009) estimate EKC for $SO_2$, suspended particles, and subtle smoke; Karahasan and Pinar (2021) for $SO_2$, $NO_2$, SPM, and deforestation; Millimet et al. (2003) for $SO_2$ and $NO_2$; Saboori and Sulaiman (2013) for $CO_2$ emissions. This study has also opted for EKC following the previous studies.

### 2.4 Ecological footprint (EF) and economic development

Studies based on different regions contribute most to explaining the relationship between EF and economic development. The study of Yang and Fan (2019), based on the survey of nine provinces in China, opines that the EF in the silk road economic belt is increasing with the increase in economic development. From the study of 11 countries from 1977 to 2013, Destek and Sarkodie (2019) argue that the role of economic development in climate change is complementary. The authors validate the EKC curve in explaining the relationship between EG and EF and opine that the relationship between them is bidirectional. Similar findings were also observed in the study of Dogan et al. (2019). From the survey of MINT countries—Mexico, Indonesia, Nigeria, and Turkey from 1971 to 2013, Dogan et al. (2019) confirm the applicability of EKC and show that EF is decreasing with the increase in trade in these MINT countries in the long run.

On the contrary, dividing the whole EF into six groups such as grazing land, cropland, fishing grounds, carbon-absorbing land, forest products, and build up the land, Aydin et al. (2019) find no existence of EKS curve in explaining the relationship between EF and subgroups of land except fishing ground. Again from the study of 50 years' time-series data of Asian countries, Uddin et al. (2019) show the mixed result in explaining the relationship between EF and EG. The authors confirm the applicability of the EKC hypothesis in Malaysia, Nepal, Pakistan, and India. However, other Asian countries depict a linear relationship between EF and economic development. Finally, the study concludes that rapid economic growth significantly influences EF and bioproductive capacity.

Form the literature survey, we observe different indicators such as $SO_2$, $NO_2$, $CO_2$, and EF, to represent the ES. Again, economic indicators like GDP per capita and trade are widely used to refer to economic development. The literature from different regions and times shows diversified outcomes such as the positive, negative association between EF and EG. On the other hand, the association of relationships also varied like linear, nonlinear, and inverted U-shaped. The study of a region also varies in outcome concerning different countries. So, in-depth review of different countries in cluster and grouping separates subsection of EF to have valuable insights yet to contribute by evidencing more empirical study.

## 3 Data and variables descriptions

This investigation uses a balanced panel dataset of 42 Asian countries from 2000 to 2017. The source of ecological footprint (EF) and biocapacity (BC) is the Global Footprint Network database from their website, and $CO_2$ emission data collect from the Organisation for Economic Co-operation and Development (OECD) website. Again, the macroeconomic data GDP per capita, foreign direct investment (FDI), unemployment rate (UR), forest area (FA) collect from the world bank database. Table 1 explains the detailed description and sources of all variables.

### 3.1 Description of variables

#### 3.1.1 Ecological footprint: concept and measurement

The pioneering work of Rees (1992) first gives an idea about the ecological footprint, which is further developed by Mathis Wackernagel, the Swiss urban planner under the supervision of Rees. Subsequently, the work of Wackernagel and Rees (1998) well articulated the concept of explaining an intelligent life of the earth.

The EF is a measurement of ecology assets such as plant-based food products, fish products, timber products, forest products, and land for building, which is required to consume by the given population, and the wastes should be absorbed by this given population as well. In other words, we can say that EF is a demand of humans on assets of ecology. Thus, EF measures the impact of human activities on natural resources like land, water, and air, which require to produce consumption goods and absorb generated waste. In this study, we use EF of consumption instead of EF production. Following the category of Global Footprint Network data, we also divide the ecological footprint into six groups. These are (1) crop land, (2) grazing land, (3) forest products, (4) fishing grounds, (5) carbon-absorbing land, and (6) buildup land. Table 1 describes each type in detail. Figure 1 depicts the graphical illustration of six groups of EF.

#### 3.1.2 Biocapacity: concept and measurement

BC refers to the productivity of ecological assets such as grazing land, cropland, buildup land, forest area, fishing grounds, and carbon emission land. It may also follow an increasing or decreasing trend like an EF. The unit of measurement of BC is also global hectares (gha). As BC refers to the assets of ecology, it is related to the region, whereas EF is related to the population. If the BC of a nation exceeds its' ecological footprint, then it is called an ecological reserve, and the reverse is called an ecological deficit. Thus, a deficit occurs when demand for environmental products such as fruits, fish, wood, meat, vegetables, and carbon dioxide absorption exceeds that country's ecosystem's capacity. Ecological deficit not only harms a particular nation or region but also becomes a burden for the whole world. Again, deficit or excessive ecological footprint is threatening the sustainability of the ecosystem. Figure 2 depicts the increasing trend of an ecological footprint from 1961 to

**Table 1** Description of variables of the study

| Classification & Variable | Description | Unit of measurement | Source |
|---|---|---|---|
| *Dependent variable* | | | |
| Ecological Footprint (EF) | lnEF<br>Ecological footprint categorizes into six divisions:<br>1. Crop land—The measurement of natural products in cropland which is needed to produce for consumption by the people<br>2. Grazing land—The measurement of natural products in grazing land, which is needed to produce for consumption by the people<br>3. Forest Products—The measurement of natural products in fishing water is needed to produce for consumption by the people<br>4. Fishing Grounds—The measurement of natural products in fishing water is needed to produce for consumption by the people<br>5. Carbon Absorbing Land—The measurement of carbon-absorbing land needs to absorb waste and $CO_2$<br>6. Buildup Land—The measure of natural assets in buildup land, which is needed to consume by the people | Global Hectares (gha) | Global Footprint Network data (https://www.footprintnetwork.org/) |
| Bio capacity (BC) | lnBC | Global Hectares (gha) | Global Footprint Network data (web: https://www.footprintnetwork.org/) |
| Carbon dioxide emissions ($CO_2$) | ln$CO_2$ | Tons | Organization for Economic Cooperation and Development data set (web: https://www.oecd-ilibrary.org/) |

**Table 1** (continued)

| Classification & Variable | Description | Unit of measurement | Source |
|---|---|---|---|
| *Independent variable* | | | |
| GDP per capita | lnGDP<br>Where GDP per capita refers to real GDP per capita<br>Real GDP per capita<br>$= \frac{\text{Nominal GDP per capita} \times 100}{\text{GDP Deflator}}$ | $ USD | World Bank data (web: http://databank.worldbank.org) |
| Foreign direct investment (FDI) | lnFDI | $ USD | World Bank data (web: http://databank.worldbank.org) &<br>International Labour Organization database (web: https://www.ilo.org/) |
| Unemployment Rate (UR) | lnUR<br>The unemployment rate refers to the percentage of the workforce unemployed from the total workforce | Percentage (%) | World Bank data (web: http://databank.worldbank.org) |
| Forest Area (FA) | lnFA | Square kilometers (sq. km.) | World Bank data (web: http://databank.worldbank.org) |

*Source* Authors' compilation using the sources mention


**Fig. 1** Measurement source of ecological footprint. *Source: Global Footprint Network* (https://www.footprintnetwork.org/our-work/ecological-footprint/)

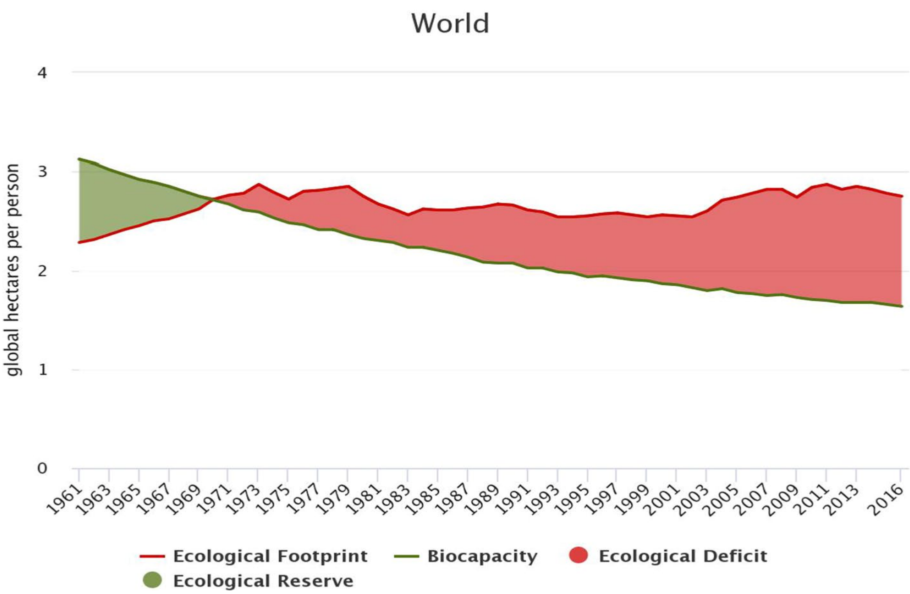


**Fig. 2** Ecological footprint and biocapacity at a global level (gha per person). *Source: Global Footprint Network website* (https://www.footprintnetwork.org/resources/data/)

2016. After 1970, the world is facing a continuous ecological deficit, increasing until 2016. Table 1 presents details of other variables and data sources used in the study.

## 4 Methods of the study

### 4.1 Ordinary least square (OLS)

Following the study of Bagliani et al. (2008), Wang et al. (2013), Baloch et al. (2019), Wang and Li (2019), Uddin et al. (2019), we also opted for ordinary least square (OLS) to examine the impact of economic progress in EF. OLS is widely accepted as an unbiased and consistent estimator. We also consider the year dummy and country with a fixed effect in regression estimates.

The model of the study is structured as follows:

$$lnEF_{it} = \beta_0 + \beta_1 lnGDP_{it} + \beta_2 lnBC_{it} + \beta_3 lnFDI_{it} + \beta_4 UR_{it} + \beta_5 lnFA_{it} + Country - effects + Time - effects + \varepsilon_{it} \quad (1)$$

where '$\beta_0$' is the intercept and '$\varepsilon_{it}$' is the error term. The subscript '$i$' refers to the cross-sectional dimension across the country, and '$t$' denotes the time dimension (i.e., $t=2000$, 2001, 2002,.., 2017).

We extend our baseline model to address the nonlinear effect of GDP per capita and observe the shape EKC curve. The extended model is as follows:

$$lnEF_{it} = \beta_0 + \beta_1 lnGDP_{it} + \beta_2 (lnGDP)^2_{it} + \beta_3 BC_{it} + \beta_4 lnFDI_{it} + \beta_5 UR_{it} + \beta_6 lnFA_{it} + Country - effects + Time - effects + \varepsilon_{it} \quad (2)$$

where $lnGDP\ per\ capita^2_{it}$ refers to the quadratic term of GDP per capita.

To observe the EF per capita of six categories of land, the model of the study is as follows:

$$lny_{it} = \beta_0 + \beta_1 lnGDP_{it} + \beta_2 (lnGDP)^2_{it} + \beta_3 BC_{it} + \beta_4 lnFDI_{it} + \beta_5 UR_{it} + \beta_6 lnFA_{it} + Country - effects + Time - effects + \varepsilon_{it} \quad (3)$$

where $y_{it}$ represents all the subgroups of EF per capita, such as buildup land, carbon-absorbing land, cropland, fishing grounds, forest products, and grazing land in '$i$' country at the time '$t$.'

### 4.2 Fully modified OLS (FMOLS)

Phillips and Moon (2000), Pedroni (2000), and Kao and Chiang (2001) offer extensions of the Phillips and Hansen (1990) fully modified OLS estimator to panel settings. Given estimates of the average long-run covariances, ₳, and $\Omega$, we may define the modified dependent variable and serial correlation correction terms

$$\bar{y}^{+}{}_{it} = \bar{y}_{it} - \acute{\omega}_{12}\, \acute{\Omega}^{-1}{}_{22}\, \hat{u}_2$$

and

$$\lambda^{+}_{12} = \lambda_{12} - \acute{\omega}_{12}\, \acute{\Omega}^{-1}_{22}\, \acute{\Lambda}_{22}$$

The FMOLS estimator is then given by

$$\beta EF = \left( \sum_{i=1}^{N} \sum_{t=1}^{T} X_{it} X_{it\prime} \right)^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} \left( X_{it} y^{+}_{it} - \lambda^{+}_{12\prime} \right) \quad (4)$$

where $EF$ is ecological footprint; $y_{it}$ and $X_{it}$ are the corresponding data purged of the individual deterministic trends; and $\acute{\omega}_{12}$ is the long-run average variance of $u_{1it}$ conditional on $u_{2it}$. In the leading case of individual-specific intercepts, $y_{it} = y_{it} - \bar{y}_i$ and $X_{\mathrm{it}} = X_{it} - \ddot{\mathrm{X}}_i$ are the demand variable.

## 5 Results and analysis

In this section, we first present the descriptive statistics and correlation matrix consisting of summary statistics of all variables and subgroups and pairwise correlations. Subsequently, we also precise supportive tests of regressions and regression results of the model equations.

### 5.1 Descriptive statistics and correlation matrix

From the summary statistics of Table 2 Panel-A, we observe that the mean (standard deviation) of EF per capita, UR, FA per capita, and $CO_2$ per capita is about 3.50 (3.20), 6.17 (4.23), 0.00447 (0.011), and 6.39e−06 (7.74e−06), respectively. The mean and standard deviation are about to be normally distributed. However, the standard deviation of real GDP per capita, BC per capita, and FDI shows a more considerable value against the mean values. That means the variability of these variables is much higher than their mean values. Moreover, the minimum value of per capita FDI and per capita $CO_2$ emissions is zero (0) due to a logarithm. Overall sample observations of the study range from 611 to 751. All variables show nonnegative values due to the positive nature of the outcomes. For example, $CO_2$ emissions per capita cannot be negative as people always emit $CO_2$ and accept $O_2$.

Panel-B and Panel-C illustrate the summary statistics of subgroups (buildup land, carbon absorbing land, crop land, fishing grounds, forest products, and grazing land) concerning EF per capita and BC per capita. The standard deviation values of Panel-B and C do not show substantial variability concerning the mean in different subgroups.

The pairwise correlation matrix of all variables is presented in Table 3. The correlation coefficient of Table 3 shows a positive relationship between EF and GDP. The coefficient 0.366 of lnBC and lnEF denotes a positive relationship that exists between per capita BC and the EF.

Correlation coefficients between independent variables in Table 3 do not show a high degree of correlation, which means no significant multicollinearity problems exist between the independent variables.

### 5.2 Supportive test for regression (stationarity test)

Basically, for time series data, researchers use the Augmented Dickey–Fuller test (Dickey & Fuller, 1979). However, there are also other stationary tests for panel data like the

**Table 2** Summary Statistics of all variables

| Variables | Obs. | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| *Panel-A* | | | | | |
| EF(gha) | 611 | 3.517 | 3.216 | 0.082 | 16.853 |
| Real GDP ($USD) | 741 | 13,897.461 | 19,061.823 | 171.122 | 109,474.405 |
| BC(gha) | 555 | 1.695 | 2.824 | 0.033 | 19.035 |
| FDI ($USD) | 715 | 601.716 | 2246.298 | 0.003 | 43,698.552 |
| UR | 756 | 6.176 | 4.236 | 0.124 | 19.019 |
| FA (Sq km) | 649 | 0.015 | 0.014 | 0.002 | 0.063 |
| $CO_2$ (tonnes) | 751 | 0.000 | 0.000 | 0.000 | 0.000 |
| *Panel-B* | | | | | |
| Buildup land | 555 | 0.062 | 0.034 | 0.000 | 0.243 |
| Carbon absorbing land | 555 | 2.648 | 2.862 | 0.077 | 15.264 |
| Crop land | 555 | 0.575 | 0.222 | 0.193 | 1.740 |
| Fishing grounds | 555 | 0.117 | 0.136 | 0.001 | 0.561 |
| Forest products | 555 | 0.197 | 0.141 | 0.005 | 0.758 |
| Grazing land | 555 | 0.243 | 0.538 | 0.001 | 4.589 |
| *Panel-C* | | | | | |
| Buildup land | 555 | 0.065 | 0.035 | 0.000 | 0.243 |
| Carbon absorbing land | 555 | 0.000 | 0.000 | 0.000 | 0.000 |
| Crop land | 555 | 0.366 | 0.314 | 0.001 | 1.998 |
| Fishing grounds | 555 | 0.344 | 0.592 | 0.003 | 4.118 |
| Forest products | 555 | 0.486 | 1.341 | 0.000 | 7.574 |
| Grazing land | 555 | 0.435 | 1.547 | 0.000 | 11.202 |

**Table 3** Pairwise Correlation matrix of the variables

| | lnEF | lnGDP | lnUR | lnFDI | lnFA | lnBC | $lnCO_2$ |
|---|---|---|---|---|---|---|---|
| lnEF | 1.000 | | | | | | |
| lnGDP | 0.642 | 1.000 | | | | | |
| lnUR | −0.098 | 0.002 | 1.000 | | | | |
| lnFDI | 0.258 | 0.337 | −0.007 | 1.000 | | | |
| lnFA | 0.103 | 0.018 | 0.099 | −0.097 | 1.000 | | |
| lnBC | 0.366 | 0.212 | 0.075 | 0.017 | 0.670 | 1.000 | |
| $lnCO_2$ | 0.645 | 0.844 | 0.023 | 0.226 | −0.003 | 0.279 | 1.000 |

Levin–Lin–Chu method, Harris–Tzavalis method, Breitung method, Im–Pesaran–Shin method, Hadri Lm stationarity method, and Fisher-type method. We opt for the Im–Pesaran–Shin method of stationary test for our panel dataset to address the missing panel data.

Following the Im–Pesaran–Shin method, the null and alternative hypotheses are as follows:

**Table 4** Unit root test of panel data (Im–Pesaran–Shin method) for all the variables

| Variables | *T*-statistics | *P*-value |
|---|---|---|
| lnEF | − 3.778 | 0.000 |
| lnGDP | − 2.887 | 0.000 |
| lnBC | − 10.145 | 0.000 |
| lnFDI | − 4.542 | 0.001 |
| lnUR | − 3.372 | 0.000 |
| lnFA | − 3.182 | 0.000 |
| $lnCO_2$ | − 3.838 | 0.000 |

**Table 5** Unit root test of panel data (Im–Pesaran–Shin method) for six categories of EF and BC per capita

| Variables | EF per capita | | BC per capita | |
|---|---|---|---|---|
| | *T*-statistics | *P*-value | *T*-statistics | *P*-value |
| ln(Buildup Land) | − 2.561 | 0.046 | − 2.758 | 0.000 |
| ln(Carbon Absorbing Land) | − 3.708 | 0.000 | No data | No data |
| ln(Cropland) | − 2.328 | 0.000 | − 2.642 | 0.004 |
| ln(Fishing Grounds) | − 4.351 | 0.000 | − 7.209 | 0.000 |
| ln(Forest Products) | − 1.859 | 0.005 | − 3.739 | 0.000 |
| ln(Grazing Land) | − 1.975 | 0.012 | − 4.895 | 0.000 |

$H_0$: Stationarity does not exist in the data of the variables.
$H_1$: Stationarity exists in the data of the variables.

Table 4 shows that all the variables, such as EF per capita, GDP per capita, BC per capita, $CO_2$ emissions per capita, FDI per capita, UR, and FA per capita, have a *p*-value near zero (0), which refers to the rejection of null hypotheses. That means all the variables are stable and stationary in this dataset.

On the other hand, Table 5 presents subgroup samples of EF per capita (BC per capita) such as buildup land, carbon-absorbing land, cropland, fishing grounds, forest products, and grazing land have *p*-value near to zero, i.e., less than 0.05.

It means all the variables have rejected the null hypothesis at a 5% level of significance and confirm the data stationarity of subgroups of EF per capita.

## 5.3 Empirical findings of the study

### 5.3.1 Effect of GDP per capita on ecological footprint (EF)

This study focuses on 42 Asian countries. The OLS estimators in Table 6 show the relation between EF per capita and GDP per capita of the full sample. From column 1, we observe that there is a significant relationship between *GDP per capita* and EF. However, no significant association is observed $ln(GDP)^2$. That means the nonlinear association is not valid here. Again, there is a significant relationship of EF with *lnGDP per capita* in column 2 in the linear model. Column 3 shows the OLS regression, depicting the effect

**Table 6** Effect of GDP per capita on Ecological Footprint per capita on 42 Asian countries

| Variables | Fixed effect | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| | lnEF | lnEF | lnEF |
| lnGDP | 0.135 | 0.156*** | 0.141*** |
| | (*0.066*) | (*0.009*) | (*0.014*) |
| $\ln(GDP)^2$ | 0.003 | – | – |
| | (*0.009*) | | |
| lnFDI | – | – | 0.021** |
| | | | (*0.007*) |
| lnUR | – | – | 0.042 |
| | | | (*0.023*) |
| lnFA | – | – | 0.078 |
| | | | (*0.073*) |
| lnBC | – | – | 0.099*** |
| | | | (*0.026*) |
| Constant | −0.183 | −0.217*** | 0.008 |
| | (*0.113*) | (*0.035*) | (*0.215*) |
| Year Dummy | Yes | Yes | Yes |
| Country Dummy | Yes | Yes | Yes |
| *N* | 600 | 600 | 510 |
| $R^2$ | 0.319 | 0.319 | 0.382 |

Ecological footprint is treated as dependent variable. We use fixed effect on regressions. Standard errors in parentheses; $*p<0.05$, $**p<0.01$, $***p<0.001$

Italics refers to probability significance at 5%, 1%, and 0.10% level, respectively

of GDP per capita on EF with some other covariates *lnFDI, lnUR, lnFA*, and *lnBC*. The finding evidences the association of EF with GDP per capita, FDI per capita, and BC per capita. The coefficient ln(GDP per capita) narrates that 14.1% of EF per capita is increased with a 1% increase in GDP per capita and also means there exists a positive linear relation between these two variables.

Again, Table 7 presents the empirical findings of examining the impact of GDP per capita on the ecological footprint in different subgroups. Column 1 and column 2 assert the outcomes of subgroup buildup land. In column 1, we observe no significant association between GDP per capita and EF. However, in column 2, these variables depict significant relationships. It means that there is a significant positive linear relationship between GDP per capita and EF. The coefficient of lnGDP per capita denotes that an increase in 1% GDP per capita EF footprint increases 21%. Similarly, columns 3–4 (columns 8–9) also precise the linear relationship between GDP per capita and EF of subgroup carbon-absorbing land (grazing land). 1% GDP growth per capita affects about 40.2% (33%) incremental EF change in carbon-absorbing land (grazing land).

However, subgroups cropland, fishing ground, and forest products validate the nonlinear relationship with GDP per capita and EF and follow an inverted U-shape curve. These findings are in line with the results of Grossman and Krueger (1995), Stern (1998), Hilton

**Table 7** Effect of GDP per capita on a subgroup of Ecological Footprint per capita

| Variables | Fixed effects | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 | Column 7 | Column 8 | Column 9 |
| | ln(Buildup Land) | ln(Buildup Land) | ln(Carbon Absorbing Land) | ln(Carbon Absorbing Land) | ln(Cropland) | ln(Fishing Grounds) | ln(Forest Prod-ucts) | ln(Grazing Land) | ln(Grazing Land) |
| lnGDP | −0.334 | 0.210*** | −0.015 | 0.402*** | 1.024*** | 2.854*** | 2.417*** | 0.684 | 0.330*** |
| | *(0.225)* | *(0.045)* | *(0.266)* | *(0.052)* | *(0.164)* | *(0.435)* | *(0.563)* | *(0.442)* | *(0.086)* |
| $\ln(GDP)^2$ | 0.081 | – | 0.062 | – | −0.124*** | −0.319*** | −0.203* | −0.052 | – |
| | *(0.033)* | | *(0.038)* | | *(0.024)* | *(0.063)* | *(0.082)* | *(0.064)* | |
| lnBC | 1.086*** | 1.027*** | 0.026 | −0.016 | 0.603*** | 0.122 | −0.048 | −0.265 | −0.229 |
| | *(0.085)* | *(0.083)* | *(0.096)* | *(0.093)* | *(0.059)* | *(0.158)* | *(0.205)* | *(0.161)* | *(0.155)* |
| lnFDI | 0.055** | 0.056** | 0.107*** | 0.108*** | −0.002 | 0.003 | −0.003 | −0.035 | −0.036 |
| | *(0.021)* | *(0.022)* | *(0.024)* | *(0.024)* | *(0.015)* | *(0.039)* | *(0.052)* | *(0.041)* | *(0.041)* |
| lnUR | 0.290*** | 0.273*** | −0.028 | −0.044 | 0.046 | 0.271* | 0.350* | 0.073 | 0.085 |
| | *(0.071)* | *(0.072)* | *(0.084)* | *(0.083)* | *(0.052)* | *(0.137)* | *(0.177)* | *(0.139)* | *(0.138)* |
| lnFA | −1.640*** | −1.594*** | 0.426 | 0.474 | −0.136 | −0.003 | 0.424 | 0.938* | 0.897* |
| | *(0.239)* | *(0.239)* | *(0.261)* | *(0.259)* | *(0.160)* | *(0.426)* | *(0.552)* | *(0.434)* | *(0.430)* |
| Constant | −7.946*** | −8.682*** | 0.654 | 0.130 | −3.060*** | −9.361*** | −6.905*** | −1.259 | −0.815 |
| | *(0.765)* | *(0.709)* | *(0.836)* | *(0.771)* | *(0.515)* | *(1.368)* | *(1.770)* | *(1.391)* | *(1.280)* |
| Year Dummy | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Country Dummy | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $N$ | 496 | 496 | 510 | 510 | 510 | 510 | 510 | 510 | 510 |
| $R^2$ | 0.401 | 0.393 | 0.341 | 0.338 | 0.384 | 0.259 | 0.277 | 0.040 | 0.038 |

Ecological footprint is treated as dependent variable. Columns 1–2 present result of buildup land, columns 3–4 represent finding of carbon-absorbing land, columns 8–9 show the results of grazing land, whereas columns 5, 6, 7 present empirical finding of cropland, fishing ground, and forest products, respectively. We use fixed effect on regressions. Standard errors in parentheses; $*p<0.05$, $**p<0.01$, $***p<0.001$

Italics refers to probability significance at 5%, 1%, and 0.10% level, respectively and Levinson (1998), List and Gallet (1999). With the increase in GDP per capita, the EF increases initially; however, in the long run, GDP growth significantly reduces the EF in cropland, fishing ground, and forest products. Panayotou (1997) pinpoints the reason behind that better economic policy, in the long run, improves the EF, and makes sure eco-friendly economic growth.

### 5.3.2 Effect of GDP per capita on biocapacity per capita

Table 8 explains the empirical findings examining the effect of GDP per capita on BC per capita for 42 Asian countries. Both linear term and nonlinear term (*lnGDP per capita* and *lnGDP per capita*$^2$) depict significance for BC per capita in column 1. Therefore, lnBC per capita is regressed on lnGDP per capita and lnGDP per capita$^2$ with other covariates like lnFDI, lnUR, and lnFA. There is still a significant coefficient of both *lnGDP per capita* and *lnGDP per capita*$^2$ in column 2.

These results (columns 1–2) support the inverted U-shaped curve in EKC in explaining the relationship between EG and biocapacity. One of the possible reasons is that with the increase in economic growth, supporting environment-friendly movements also increases. However, in the long run, the economic growth pressure inversely affects the BC capacity per capita. The coefficient of BC per capita (in column 2) shows that 76% BC increase

**Table 8** Effect of GDP per capita on biocapacity per capita

| Variables | Fixed Effects | |
|---|---|---|
| | (1) | (2) |
| | lnBC | lnBC |
| lnGDP | 1.462*** | 0.760*** |
| | (0.168) | (0.120) |
| ln(GDP)$^2$ | −0.230*** | −0.107*** |
| | (0.024) | (0.017) |
| lnEA | – | 0.299*** |
| | | (0.076) |
| lnFDI | – | −0.003 |
| | | (0.012) |
| lnUR | – | −0.121** |
| | | (0.039) |
| lnFA | – | 1.708*** |
| | | (0.094) |
| Constant | −2.224*** | 3.874*** |
| | (0.288) | (0.351) |
| Year dummy | Yes | Yes |
| Country dummy | Yes | Yes |
| *N* | 548 | 510 |
| $R^2$ | 0.185 | 0.507 |

Biocapacity per capita is the dependent variable. We use a fixed effect on regressions. Standard errors in parentheses; *$p<0.05$, **$p<0.01$, ***$p<0.001$

**Table 9** Effect of GDP per capita on a subgroup of biocapacity per capita

| Variables | Fixed Effects | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | ln(Buildup Land) | ln(Buildup Land) | ln(Crop land) | ln(Fishing Grounds) | ln(Forest Products) | ln(Grazing Land) |
| lnGDP | 0.504* | 0.239*** | 1.191*** | 0.495*** | 0.096*** | 0.443*** |
| | (0.249) | (0.056) | (0.240) | (0.065) | (0.018) | (0.105) |
| $\ln(GDP)^2$ | −0.039 | | −0.149*** | −0.089*** | −0.016*** | −0.093*** |
| | (0.036) | | (0.035) | (0.009) | (0.003) | (0.015) |
| lnEF | 0.158 | 0.160 | 0.650*** | 0.177*** | −0.009 | 0.532*** |
| | (0.160) | (0.160) | (0.153) | (0.042) | (0.012) | (0.067) |
| lnFDI | 0.045 | 0.045 | 0.034 | −0.007 | −0.001 | −0.004 |
| | (0.025) | (0.025) | (0.023) | (0.006) | (0.002) | (0.009) |
| lnUR | 0.182* | 0.190* | 0.021 | −0.153*** | −0.024*** | −0.150*** |
| | (0.083) | (0.082) | (0.078) | (0.021) | (0.006) | (0.033) |
| lnFA | −0.331 | −0.316 | 2.506*** | 2.049*** | 2.383*** | 1.822*** |
| | (0.246) | (0.246) | (0.188) | (0.051) | (0.014) | (0.079) |
| Constant | −5.380*** | −4.908*** | 3.576*** | 3.369*** | 4.639*** | 1.847*** |
| | (0.847) | (0.728) | (0.701) | (0.189) | (0.054) | (0.289) |
| Year Dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Country Dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| $N$ | 496 | 496 | 510 | 510 | 510 | 480 |
| $R^2$ | 0.192 | 0.190 | 0.373 | 0.860 | 0.988 | 0.706 |

Biocapacity per capita is the dependent variable. Columns 1–2 present the result of buildup land; columns 3, 4, 5, and 6 represent the findings of cropland, fishing ground, forest products, and grazing land, respectively. We use a fixed effect on regressions. Standard errors in parentheses; $*p<0.05$, $**p<0.01$, $***p<0.001$

with 1% increase in GDP per capita; later BC per capita is decreased by 10.7% with a 1% increase in GDP per capita in column 2.

The effect of GDP per capita on BC per capital is also examined on different subgroups, and Table 9 presents the empirical finding. Table 9 examines the effect of GDP per capita with other covariates on five categories of BC per capita. However, we are not reporting the results of another subgroup, Carbon Absorbing Land, as we did not find any outcomes due to missing data. The empirical finding of the study validates linear relationship only in subgroup build up land, whereas other subgroups show the significant nonlinear association of GDP per capita and biocapacity. The coefficient of lnGDP per capita 0.239 in column 2 proves that BC per capita on buildup land is increased by 23.9%, with a 1% increase in GDP per capita. Therefore, there is a significant positive linear relationship between per capita GDP and per capita EF on buildup land.

However, in columns 3, 4, 5, and 6 the coefficients of *lnGDP per capita* and *lnGDP per capita*$^2$ both are significantly associated with BC per capita on cropland, BC per capita on fishing grounds, BC per capita on forest products, and BC per capita on grazing land. It means that there is a nonlinear relationship between GDP per capita and BC per capita on cropland; between GDP per capita and BC per capita on fishing grounds; between GDP per capita and BC per capita on forest products; between GDP per capita and EF per capita on grazing land. These results align with the aggregate sample results and reinforce the inverted U-shape EKC curve in explaining the relationship between GDP per capita and biocapacity.

### 5.4 Cointegration analysis

Table 10 reports the long-term cointegration for each country obtained using the FMOLS model developed by Pedroni (2000). The advantages of the FMOLS model are that this is flexible to preserve the parameters' precision, even though heterogeneity exists between the panels. For GDP, the impact on EF is significant at 0.05% in these eleven countries, such as China, India, Iran, Lebanon, Mongolia, Pakistan, Russia, Singapore, Syria, Tajikistan, and Turkey. The vector strength is highest in Iran and Singapore. The FDI effect on EF is minimal in most of the 42 countries. FDI facilitates cooperation between countries in constructing energy infrastructure between various countries. Only the long-term coefficient of Thailand is the highest. We find that from 18 to 42 countries, the long-term coefficient of FDI is negative, and in some countries, it is greater than 1. We also find that the impact of the unemployment rate UR on EF is heterogeneous among 42 countries. The result shows that from 28 out of 42 countries, the long-term coefficient is negative, and in some countries, it is greater than 1. Oman is considered the highest long-run value for the unemployment rate, which indicates that EF creates more employment opportunities in those countries by utilizing human capital.

At the same time, FA does constitute an economic policy option to curb the consumption of the primary source of global warming. However, energy integration has some geopolitical concerns that can limit broad integration between countries. Most of the long-term elasticity of EF output for FA is positive and significant. Brunei and Qatar constitute the highest long-term FA coefficient. The reduction in energy consumption from polluting sources can be explained by the more significant environmental awareness of the population when it is highly concentrated. The importance of reducing carbon dioxide emissions caused by non-renewable energy may be more widespread if the population lives in urban

**Table 10** Results from cointegration coefficients FMOLS long-run analysis

| Countries | GDP | *t*-statistics | FDI | *t*-statistics | UR | *t*-statistics | FA | *t*-statistics | $CO_2$ | *t*-statistics | BC | *t*-statistics |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Armenia | 0.11 (*0.149*) | 1.56 | −0.01 (*0.731*) | −0.35 | −0.16 (*0.431*) | −0.82 | −44.99 (*0.002*) | −4.02 | 0.32 (*0.022*) | 2.71 | 0.21 (*0.065*) | 2.07 |
| Azerbaijan | −0.06 (*0.255*) | −1.21 | 0.02 (*0.643*) | 0.47 | −0.45 (*0.108*) | −1.76 | −0.54 (*0.072*) | −2.02 | 0.24 (*0.16*) | 1.52 | −0.06 (*0.685*) | −0.42 |
| Bahrain | −0.03 (*0.951*) | −0.06 | −0.01 (*0.743*) | −0.33 | −0.46 (*0.645*) | −0.47 | −3.68 (*0.000*) | −5.43 | 1.01 (*0.153*) | 1.54 | −1.22 (*0.048*) | −2.24 |
| Bangladesh | −0.12 (*0.162*) | −1.51 | 0.01 (*0.251*) | 1.217 | −0.06 (*0.218*) | −1.32 | 0.32 (*0.965*) | 0.04 | 0.46 (*0.027*) | 2.58 | 0.63 (*0.024*) | 2.65 |
| Brunei | 0.28 (*0.109*) | 1.75 | −0.05 (*0.246*) | −1.23 | 0.42 (*0.580*) | 0.57 | 16.75 (*0.138*) | 1.60 | 0.38 (*0.191*) | 1.40 | −0.36 (*0.118*) | −1.70 |
| China | 0.11 (*0.014*) | 2.95 | −0.06 (*0.057*) | −2.14 | −0.04 (*0.703*) | −0.39 | −0.02 (*0.973*) | −0.033 | 0.51 (*0.000*) | 5.13 | 0.19 (*0.283*) | 1.13 |
| Cambodia | −0.06 (*0.638*) | −0.48 | 0.05 (*0.034*) | 2.44 | −0.01 (*0.906*) | −0.120 | −1.40 (*0.143*) | −1.58 | 0.07 (*0.226*) | 1.29 | −0.56 (*0.176*) | −1.45 |
| Cyprus | −0.63 (*0.236*) | −1.25 | 0.13 (*0.000*) | 4.71 | −0.42 (*0.019*) | −2.77 | 59.50 (*0.330*) | 1.02 | 1.81 (*0.014*) | 2.93 | 0.11 (*0.903*) | 0.12 |
| Georgia | 0.18 (*0.393*) | 0.89 | 0.01 (*0.995*) | 0.01 | −0.55 (*0.086*) | −1.90 | −1.93 (*0.757*) | −0.31 | 0.19 (*0.283*) | 1.13 | 0.01 (*0.973*) | 0.03 |
| India | 0.12 (*0.024*) | 2.64 | 0.01 (*0.261*) | 1.19 | 0.02 (*0.710*) | 0.38 | −1.41 (*0.168*) | −1.48 | 0.38 (*0.000*) | 8.08 | 0.28 (*0.006*) | 3.39 |
| Indonesia | −0.02 (*0.625*) | −0.50 | −0.01 (*0.465*) | −0.76 | −0.01 (*0.757*) | −0.32 | −1.65 (*0.015*) | −2.92 | 0.14 (*0.308*) | 1.07 | 0.04 (*0.072*) | 2.01 |
| Iran | 0.75 (*0.000*) | 5.83 | 0.04 (*0.523*) | 0.66 | −0.74 (*0.022*) | −2.70 | −2.68 (*0.244*) | −1.24 | −2.65 (*0.006*) | −3.45 | 2.23 (*0.002*) | 3.96 |
| Iraq | 0.16 (*0.103*) | 1.79 | −0.08 (*0.000*) | −5.98 | 0.25 (*0.64*) | 0.47 | −16.32 (*0.572*) | −0.58 | 1.03 (*0.000*) | 6.24 | −0.01 (*0.971*) | −0.02 |
| Israel | 0.63 (*0.231*) | 1.29 | 0.05 (*0.418*) | 0.85 | 0.41 (*0.49*) | 0.71 | 3.54 (*0.293*) | 1.13 | 2.04 (*0.022*) | 3.19 | 0.31 (0.426) | 0.83 |
| Japan | −0.01 (*0.961*) | −0.05 | −0.01 (*0.296*) | −1.11 | −0.01 (*0.682*) | −0.42 | −6.41 (*0.492*) | −0.71 | 0.45 (*0.001*) | 4.54 | 1.10 (*0.001*) | 4.54 |

**Table 10** (continued)

| Countries | GDP | *t*-statistics | FDI | *t*-statistics | UR | *t*-statistics | FA | *t*-statistics | $CO_2$ | *t*-statistics | BC | *t*-statistics |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jordan | 0.21 (0.000) | 6.02 | 0.03 (*0.065*) | 2.06 | 0.19 (*0.106*) | 1.77 | −0.03 (*0.042*) | −2.33 | 0.92 (*0.000*) | 5.53 | 0.72 (*0.005*) | 3.51 |
| Kazakhstan | 0.06 (*0.597*) | 0.54 | 0.08 (*0.086*) | 1.90 | −0.34 (*0.316*) | −1.05 | 13.59 (*0.347*) | 0.99 | 0.58 (*0.157*) | 1.52 | 0.29 (*0.394*) | 0.89 |
| Kuwait | 0.08 (*0.213*) | 1.32 | −0.02 (*0.014*) | −2.94 | 0.15 (*0.021*) | 2.71 | 1.13 (*0.000*) | 4.94 | 2.03 (*0.000*) | 10.03 | 0.01 (*0.674*) | 0.43 |
| Kyrgyzstan | −0.14 (*0.174*) | −1.46 | 0.02 (*0.265*) | 1.18 | −0.21 (*0.055*) | −2.16 | −1.12 (*0.000*) | −4.87 | 0.42 (*0.003*) | 3.80 | −0.09 (*0.702*) | −0.39 |
| Lebanon | 0.62 (*0.003*) | 3.81 | 0.04 (*0.298*) | 1.09 | 0.25 (*0.542*) | 0.63 | −3.16 (*0.224*) | −1.29 | 0.22 (*0.416*) | 0.84 | 0.41 (*0.000*) | 6.02 |
| Malaysia | −0.31 (*0.144*) | −1.58 | 0.02 (*0.242*) | 1.24 | −0.12 (*0.743*) | −0.34 | −0.71 (*0.640*) | −0.48 | 1.18 (*0.021*) | 2.72 | −0.38 (*0.064*) | −2.07 |
| Mongolia | −0.28 (*0.036*) | −2.40 | −0.01 (*0.238*) | −1.25 | −0.03 (*0.669*) | −0.43 | 1.93 (*0.030*) | 2.52 | 0.79 (*0.051*) | 2.21 | −0.47 (*0.001*) | −4.34 |
| Myanmar | −0.03 (*0.542*) | −0.63 | −0.01 (*0.622*) | −0.50 | −1.92 (*0.041*) | −2.33 | 0.48 (*0.585*) | 0.56 | −0.08 (*0.404*) | −0.86 | −0.04 (*0.000*) | −4.64 |
| Nepal | 0.02 (*0.738*) | 0.34 | −0.01 (*0.258*) | −1.19 | 0.08 (*0.065*) | 2.07 | −1.07 (*0.061*) | −2.11 | 0.07 (*0.084*) | 1.92 | −0.05 (*0.244*) | −1.24 |
| Oman | 0.06 (*0.773*) | 0.29 | 0.03 (*0.169*) | 1.48 | 1.27 (*0.079*) | 1.95 | 0.04 (*0.567*) | 0.59 | 0.68 (*0.116*) | 1.71 | 1.21 (*0.273*) | 1.15 |
| Pakistan | 0.07 (*0.029*) | 2.54 | 0.03 (*0.000*) | 6.12 | −0.01 (*0.084*) | −1.91 | 0.26 (*0.005*) | 3.55 | 0.13 (*0.167*) | 1.48 | 0.62 (*0.000*) | 8.67 |
| Philippines | −0.03 (*0.494*) | −0.70 | −0.01 (*0.834*) | −0.21 | −0.07 (*0.200*) | −1.37 | −0.14 (*0.718*) | −0.37 | −0.36 (*0.023*) | −2.67 | 0.02 (*0.316*) | 1.05 |
| Qatar | 0.21 (*0.100*) | 1.80 | 0.03 (*0.314*) | 1.05 | −0.33 (*0.062*) | −2.09 | 20.68 (*0.108*) | 1.76 | 0.44 (*0.506*) | 0.68 | −3.24 (*0.185*) | −1.42 |
| Russia | −0.12 (*0.008*) | −3.29 | 0.01 (*0.233*) | 1.26 | −0.16 (*0.001*) | −4.48 | 0.92 (*0.815*) | 0.23 | 0.81 (*0.000*) | 4.73 | −0.03 (*0.005*) | −3.52 |

**Table 10** (continued)

| Countries | GDP | *t*-statistics | FDI | *t*-statistics | UR | *t*-statistics | FA | *t*-statistics | $CO_2$ | *t*-statistics | BC | *t*-statistics |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Saudi Arabia | −0.04 (*0.155*) | −1.53 | −0.01 (*0.936*) | −0.08 | 0.01 (*0.919*) | 0.11 | −0.01 (*0.073*) | −1.99 | 0.33 (*0.002*) | 4.06 | 0.12 (*0.000*) | 6.47 |
| Singapore | 0.60 (*0.000*) | 8.17 | 0.01 (*0.866*) | 0.17 | 0.24 (*0.001*) | 4.38 | 0.05 (*0.056*) | 2.16 | 0.04 (*0.884*) | 0.14 | −11.96 (0.000) | −10.08 |
| South Korea | −0.44 (*0.131*) | −1.64 | −0.15 (*0.040*) | −2.34 | −0.57 (*0.136*) | −1.61 | −7.27 (*0.683*) | −0.41 | 1.16 (*0.105*) | 1.78 | −0.28 (*0.028*) | −2.56 |
| Sri Lanka | 0.12 (*0.067*) | 2.05 | 0.03 (*0.270*) | 1.16 | 0.13 (*0.235*) | 1.26 | 2.56 (*0.092*) | 1.85 | 0.14 (0.000) | 5.01 | −0.55 (0.002) | −4.03 |
| Syria | −0.91 (*0.000*) | −6.96 | 0.05 (*0.307*) | 1.07 | −0.02 (*0.743*) | −0.33 | 6.06 (*0.000*) | 5.42 | 0.15 (0.068) | 2.03 | −0.52 (0.082) | −1.92 |
| Tajikistan | 0.14 (*0.001*) | 4.32 | −0.03 (*0.001*) | −4.24 | 0.19 (*0.58*) | 0.57 | −13.77 (*0.099*) | −1.81 | 0.39 (0.001) | 4.55 | 0.06 (0.214) | 1.32 |
| Thiland | −0.06 (*0.390*) | −0.89 | 8.66 (*0.999*) | 0.01 | −0.01 (*0.960*) | −0.05 | 0.58 (*0.632*) | 0.49 | 1.04 (0.006) | 3.44 | −0.02 (0.89) | −0.13 |
| Turkey | 0.27 (*0.000*) | 8.64 | −0.03 (*0.022*) | −2.69 | −0.07 (*0.095*) | −1.84 | −0.63 (*0.112*) | −1.70 | 0.52 (0.006) | 3.43 | 0.20 (0.003) | 3.75 |
| Turkmenistan | −0.02 (*0.639*) | −0.48 | −0.01 (*0.923*) | −0.09 | −0.15 (*0.477*) | −0.73 | 0.01 (*0.639*) | 0.48 | 0.91 (0.000) | 6.71 | 0.24 (0.004) | 3.68 |
| UAE | 0.04 (*0.730*) | 0.35 | −0.02 (*0.175*) | −1.47 | −0.07 (*0.688*) | −0.41 | −13.50 (*0.111*) | −1.76 | 1.66 (0.002) | 4.26 | −0.29 (0.086) | −1.92 |
| Uzbekistan | 0.03 (*0.320*) | 1.04 | 0.01 (*0.514*) | 0.67 | −0.04 (*0.888*) | −0.14 | 0.84 (*0.290*) | 1.11 | 0.38 (0.003) | 3.76 | −0.03 (0.057) | −2.14 |
| Vietnam | −0.20 (*0.050*) | −2.22 | 0.08 (*0.000*) | 4.85 | −0.01 (*0.827*) | −0.22 | 3.71 (*0.001*) | 4.52 | −0.07 (0.21) | −1.32 | 0.03 (0.770) | 0.29 |
| Yemen | −0.09 (*0.090*) | −1.87 | 0.02 (*0.051*) | 2.21 | −0.27 (*0.081*) | −1.93 | 0.01 (*0.700*) | 0.39 | 0.04 (0.478) | 0.73 | 0.84 (0.001) | 4.50 |

Estimation result of FMOLS model. Models are estimated with the entire in-sample in the upper panel. *P*-values for the statistical significance of the coefficients are given in parentheses

Italics refers to probability significance at 5%, 1%, and 0.10% level, respectively centers. The long-term elasticity of the EF output for $CO_2$ is positive and significant. In China, Russia, Israel, and the UAE, the long-term coefficient is strong.

Similarly, in most Asian countries, the human capital index's impact on non-renewable energy consumption is negative. We found that, in Japan, Iran, and Oman, the coefficient is greater than 1, indicating that the impact of BC on EF is high. In general, these results reveal that per capita output is not a mechanism for reducing energy from fossil sources. Finally, we find that the long-term coefficient that measures the impact of services on EF is negative in most countries, but it is small. Our results suggest that other factors also explain the levels and patterns of economic development from EF.

### 5.5 Robustness analysis

We again perform regressions consecutively by using an alternative measure of ecological pressure, i.e., $CO_2$ emissions per capita as a dependent variable instead of EF per capita. The robust estimation results are presented in Table 11, demonstrating the regression of alternative outcomes for the OLS estimation. GDP per capita is the significant explanatory variable of $CO_2$ emissions per capita. It is known that if EF per capita is increased, then carbon-absorbing land will be decreased; thus, per capita, $CO_2$ emissions will be raised, which represents the positive correlation between EF per capita and $CO_2$ emissions per capita. So, in this case, if there is the same result as EF per capita, then it could be said that the results are more realistic, and the model is robust. The key results are robust after considering an alternative measure of EF. The evaluation results for coefficients of lnGDP per capita are plausible, and both EF per capita and $CO_2$ emission per capital estimation evidence a linear relationship with GDP per capita.

### 5.6 Residual test

The empirical results of the CD analysis are demonstrated in Table 12. For panels data, the statistically significant Pesaran and Breusch–Pagan LM tests of CD analysis reject the null hypothesis of the cross-sectional independence and assure the existence of the cross-sectional dependence.

## 6 Discussion

The present study was designed to investigate the impact of economic development on environmental sustainability and measure the long-term effects of economic growth on environmental degradation in the listed Asian countries. Concerning the first research question, it was found that EF per capita is increasing gradually from the initiation of the year 2000 (Fig. 3). The increasing linear trend of EF per capital is like a red alarm for Asian countries and indicates the chronological worsen the environment's situation. However, GDP per capita does not show an increasing linear trend in Asia during 2000–2017 (see Fig. 4). For example, from the 2000–2001 time period, the GDP per capita growth rate has been decreased by (3.55–10.31) = −6.76 units in Asia. But during the 2001–2002 time period, the GDP per capita growth rate has been increased by (4.82–3.55) = 1.27 units. Then, it follows an increasing trend till 2004; after that, it decreases again as we see in Fig. 4. Thus, GDP per capita growth rate in Asian countries depicts a nonlinear trend. The findings of this study reveal that there is a significant positive linear relationship between GDP per capita and EF. This study is in line with Udemba (2018), Ahmed et al. (2021a), Uddin et al. (2019), Destek and Sarkodie (2019). However, Aşıcı and Acar (2016), Kasman and Duman (2015); Acar and Aşıcı (2017); Wang et al. (2016) provide mixed findings which are contradictory to our results.

Aşıcı and Acar (2016) show the relationship between income per capita and ecological footprint of production. In the case of the footprint of imports, the estimated income turning points are out of the income range of the sample. This supports our hypothesis that as countries grow richer, they tend to export the ecological cost of their consumption to poorer economies. Acar and Aşıcı (2017) Regarding consumption footprint, this reveals the fact that Turkey is still on the ascending side of the curve concerning income. These results suggest that Turkey has already started to export the negative consequences of its consumption by importing rather than domestically producing environmentally harmful products. Baz et al. (2020) No causality run from the EF to GDP in both cases, asymmetric and symmetric. The finding also shows no causal link runs from GDP to the EF about asymmetric causality. Thus, this research finds the research question of whether GDP per capita is responsible for increasing EF per capita or not.

**Table 11** Effect of GDP per capita on $CO_2$ emissions per capita

| Variables | Fixed effects | |
|---|---|---|
| | (1) | (2) |
| | $\ln CO_2$ | $\ln CO_2$ |
| lnGDP | 0.194* | 0.101*** |
| | (0.075) | (0.016) |
| $\ln(GDP)^2$ | −0.014 | – |
| | (0.011) | |
| lnEA | 0.574*** | 0.572*** |
| | (0.047) | (0.047) |
| lnFDI | 0.014 | 0.014 |
| | (0.007) | (0.007) |
| lnUR | −0.011 | −0.007 |
| | (0.024) | (0.024) |
| lnFA | 0.293*** | 0.282*** |
| | (0.074) | (0.074) |
| lnBC | −0.079** | −0.069** |
| | (0.028) | (0.027) |
| Constant | −5.348*** | −5.231*** |
| | (0.237) | (0.218) |
| Year Dummy | Yes | Yes |
| Country Dummy | Yes | Yes |
| $N$ | 510 | 510 |
| $R^2$ | 0.541 | 0.540 |

$CO_2$ emissions per capita is the dependent variable. We use a fixed effect on regressions. Standard errors in parentheses; $*p<0.05$, $**p<0.01$, $***p<0.001$

**Table 12** Results from the cross-sectional dependency (CD) analysis

| Tests | Result |
|---|---|
| Pesaran CD | 3.732* |
| Breusch–Pagan LM | 19.261** |

*, ** refers statistical significance at 5%, and 1%, respectively

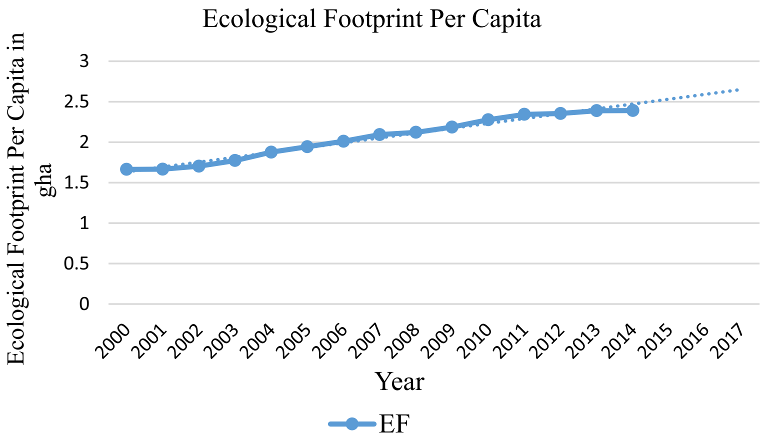


**Fig. 3** Annual ecological footprint per capita in gha in 42 Asian countries. *Source: Global Footprint Network* (https://www.footprintnetwork.org/)

Based on research question 2, Fig. 5 depicts that BC per capita is also nonlinear in Asia during the 2000–2017 period, which means that BC per capita sometimes increases, whereas sometimes it also decreases.

For example, from the 2000–2003 time period, BC per capita has been decreased by $\left[\frac{0.7905-0.8067}{0.8067}\right] \times 100 = -2.01\%$ in Asia. But during the 2003–2004 time period, BC per capita has been increased by $\left[\frac{0.8012-0.7905}{0.7905}\right] \times 100 = 1.35\%$ in Asia. Then, it was decreased again till 2005; after that, it was increased again during the 2005–2007 time period. Finally, it can be said that these figures show a nonlinear curve in the graph, as shown in Figs. 4 and 5.

These results in Table 8 (columns 1–2) support the inverted U-shaped curve in EKC in explaining the relationship between EG and biocapacity. One of the possible reasons is that with the increase in economic growth, supporting environment-friendly movements also increases. However, in the long run, the economic growth pressure inversely affects the BC capacity per capita. The effect of GDP per capita on BC per capital was also examined on different subgroups, and Table 9 presents the empirical finding. The empirical finding of the study validates linear relationship only in subgroup build up land, whereas other subgroups show the significant nonlinear association of GDP per capita and biocapacity. The coefficient of lnGDP per capita 0.239 in column 2 proves that BC per capita on buildup land is increased by 23.9%, with a 1% increase in GDP per capita. Therefore, there is a significant positive linear relationship between per capita GDP and per capita EF on buildup land. The findings of this study are similar to Ahmed et al. (2021b), Gabbi et al. (2021), Marti and Puertas (2020), and Niccolucci et al. (2012). However, Aşıcı (2015) and Nathaniel (2020) show the opposite results which indicate that economy cannot grow without running not only current accounts but also biocapacity deficit.

For research question 3, we use the cointegration model to examine the single country effect of ecological footprint and economic development. Most Asian countries have a significant economic impact on their ecological footprint. However, FDI shows less effect on EF in most of these countries. Only Thailand contributes the highest long-term coefficient value. FDI facilitates cooperation between countries in constructing energy infrastructure between various countries. On the other hand, EF and $CO_2$ emissions per capita in Asia follow a growing linear trend, and both are positively correlated with each other. The effect of GDP per capita on both per capita EF and per capita $CO_2$ emissions is similar. We also found that Japan, Iran, and Oman have a coefficient value greater than 1, indicating that the impact of BC on EF is high. Our empirical findings are also in line with Ahmad et al. (2021); Aydin et al. (2019); Dogan et al. (2019) and Hassan et al. (2018). Therefore, we may conclude that environmental sustainability exists in Asian countries.

## 7 Conclusion

The environment is the most significant issue in sustainable growth and development in the present world. Population control is a great challenge for environmental protection and ecological balance. Again, EG is also essential for the development of a nation. Thus, Asia, the most populous and fast-growing economic region globally, becomes a considering plot of study for researchers, regulators, policymakers, stakeholders, and development partners. Population density and environmental degradation are positively associated. Again, economic development inversely affects the environment (Andreoni & Levinson, 2001; Dinda, 2004). As a populous region and economic giant, examining the relationship between economic development and environmental sustainability is more evident for Asia than the rest of the world (Hall, 2002; Le et al., 2019).

This study investigates the impact of economic development on ED and ES. This study uses per capita gross domestic products as economic development indicators and per capita EF, $CO_2$ emissions, BC as environmental indicators from 2000 to 2017. We observe

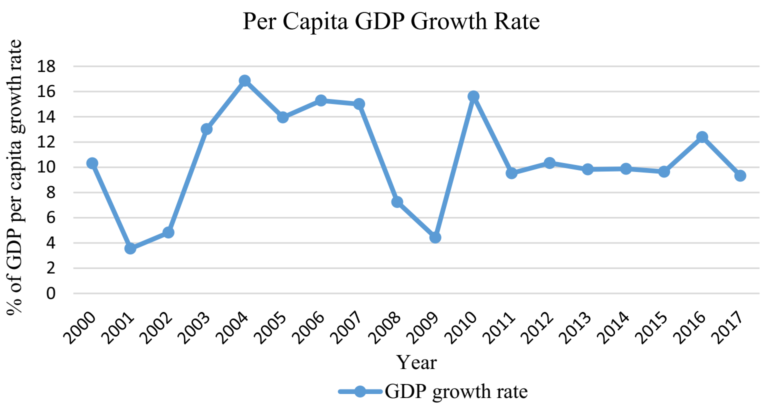


**Fig. 4** Percentage of annual per capita GDP growth rate in 42 Asian countries. *Source: Authors' compilation using World Bank data set* (http://databank.worldbank.org)

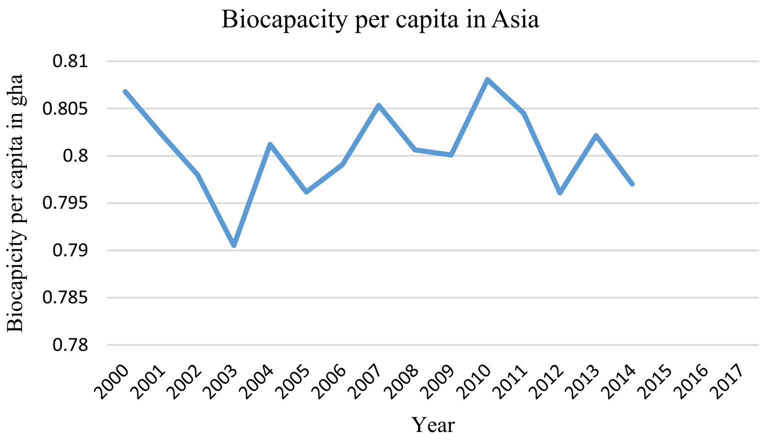


**Fig. 5** Annual biocapacity per capita (in gha). *Source: Global Footprint Network (web:* https://www.footprintnetwork.org/*)*

the positive linear relationship between EG and EF, which means that human activities or human demand on the environment increase in the Asian region. On the contrary, the relationship between per capita GDP and per capita BC shows a significant inverted U-shaped EKC curve in Asia, which means the bioproduct generation capacity of biological areas is increasing initially and then decreasing in the long run. The whole scenario leads to the unsustainability of the environment in the Asian region and the entire world at large. Human demand for nature is growing with economic development, but natural supply is not increasing with economic growth. In a word, we can say that there is a negative impact of GDP per capita on ES because of inconsistent ecological balance. This red signal for stopping environmental degradation has significant implications for policymakers in Asian countries. Policymakers need to strike a balance between economic development and ES. The FMOLS model results suggest that the impact of output, FDI, UR, and $CO_2$ is heterogeneous among Asian countries. In general, long-term estimators confirm the threshold regression model results: increases in real per capita output do not solve the problem of EF, while FA and BC reduce polluting energy in most of the countries analyzed.

### 7.1 Policy recommendations and future research

Based on the findings, we recommend some essential policies to protect and increase environmental biocapacity and lower the EF. Firstly, Asian countries should especially receive responses against incremental environmental degradation, and these countries should develop and implement policies to reduce the EF and higher the biocapacity. Secondly, this study finds the heterogeneous impact of EG on the EF in different subgroups. For example, a positive linear relationship between EF and GDP per capita observes for buildup land, carbon-absorbing land, and grazing land. Cropland, fishing grounds, and forest products reflect a non-linearity with an inverted U-shaped EKC curve. It means that uniform policies will not work for all subgroups. Again, the subgroup of biocapacity evidences non-linear relationship with economic development in cropland, fishing grounds, forest products, and grazing land following an inverted U-shaped EKC curve. However, buildup land depicts a positive linear relationship between GDP growth and BC. In a nutshell, we can say that the relationship between EG and ES is not a balanced one. This imbalance will not only harm the long-term sustainability in Asia but also will shake the world for further sustainable growth. Finally, when the population is densely concentrated, the reduction in energy consumption from environmental pollutants can be explained by the people's increased environmental consciousness. If the population resides in cities, the need of lowering carbon dioxide emissions generated by non-renewable energy may be more widely recognized. The long-term elasticity of the EF output for $CO_2$ is positive and significant which indicates that China, Russia, Israel, and the UAE need more focus on balancing ecological footprint.

Our study has the following limitations: first, the most up-to-date information for energy consumption and $CO_2$ emissions is not available which is very essential to measure the current scenario. Second, our study is only limited to cointegration analysis; however, the casualty test can provide more reliable results for policy implementation at a single country level. Thirdly, due to the econometric analysis, the impact of environmental sustainability variables on sustainable development goals 2030 is not properly addressed. Therefore, it is high time for the Asian region to be more concerned regarding ES and manage the EF, carbon emission at a reasonable rate with EG. Further study can be extended by focusing the comparative research between developed world scenarios and developing economic scenarios on the titled study.

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