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Research article

Effects of human inequality and urbanization on ecological well-being performance: A System-GMM analysis

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ABSTRACT

Enhancing the efficiency with which ecological consumption is transformed into human well-being is a necessary condition for achieving sustainable development. However, the current literature lacks systematic methods and applications for scientifically assessing Ecological Well-being Performance (EWP). How to value and index EWP is crucial to improve EWP. This study combines the Human Development Index (HDI), Life Satisfaction (LS), and Ecological Footprint (EF) to construct a new Index of Ecological Well-being Performance (IEWP). Meanwhile, human inequality and urbanization are two common and profound socio-economic phenomena with potential impacts on EWP. Therefore, this study uses panel data for 129 countries from 2010 to 2021 and applies the System-GMM approach to explore the impact of human inequality, urbanization, and the interaction between these two factors on EWP. Our results show that EWP has a cumulative effect in the long run. Human inequality has a negative effect on EWP, while the effect of urbanization is positive. Compared to developed countries, the negative impact of human inequality and the positive impact of urbanization are more pronounced in emerging and developing countries. This paper further reveals that the interaction term inhibits EWP, which indicates that urbanization exacerbates the negative effect of human inequality and that human inequality weakens the positive effect of urbanization. This paper contributes to understanding how human inequality and urbanization affect sustainable development from the perspective of EWP.

1. Introduction

Achieving a higher level of human well-being within ecological carrying capacity is the basic requirement of sustainable development. By applying Daly's "Ends-Means Spectrum" [1], sustainable development focuses on the ultimate ends (human well-being) and ultimate means (ecological consumption), arguing that human beings should ultimately increase human well-being within ecological limits. On the one hand, natural capital is irreplaceable and scarce in a "full world". However, the continuous expansion of the economy leads to a decrease in natural capital and an excessive increase in waste emissions. This causes ecological consumption to inevitably dimmish and even face biophysical limits. According to Richardson et al. [2], human activities have transgressed six of nine

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planetary boundaries. Under uncertain global environmental conditions, human activities have seriously interfered with the stability and resilience of the Earth system. To maintain ecological sustainability, enhancing human well-being is the ultimate goal that people should pursue. On the other hand, ecological consumption supports human life activities from both sources (meaning the generation of material and energy) and sinks (meaning the absorption of waste). Yet, as human activities continuously exceed ecological limits, ecological consumption cannot be efficiently converted into well-being, constraining its enhancement. Hence, improving the efficiency of converting ecological consumption into human well-being with ecological limits is a necessary condition for achieving sustainable development.

Ecological Well-being Performance (hereafter EWP) denotes the efficiency of converting ecological consumption into human well-being [3]. With this definition, the ultimate purpose of EWP is to maximize human well-being with minimal ecological consumption. Comparably, Eco-efficiency is a similar but distinct concept from EWP. Traditionally, Eco-efficiency deals with the conversion of natural consumption into economic growth [4]. However, this is a narrow view. Economic growth is only an intermediate means. Enhancing well-being is the ultimate goal of human development. In contrast, EWP emphasizes achieving and improving human well-being. Here, human well-being is broad in scope, representing not only natural materials and energy but also encompassing ecosystem services. Ecological sustainability and socio-economic well-being are the two essential aims of EWP. Enhancing EWP can contribute to achieving long-term human well-being within ecological limits.

There are various approaches regarding the measurement of EWP. Initially, Daly [1] adopts the ratio of service to throughput to reflect the efficiency of the ultimate means (ecological consumption) into the ultimate end (well-being improvement). With the depth of research, scholars apply the input-output method to construct a comprehensive indicator evaluation system to assess EWP [5,6]. Moreover, some scholars measure EWP by questionnaire surveys [7,8]. However, most studies assess EWP from a static perspective, ignoring the fact that EWP is a dynamic efficiency value. It puts more emphasis on the ability and efficiency of transforming ecological consumption into well-being. Therefore, one of the objectives of this study is to select reasonable, reliable, and effective indicators to assess EWP. Based on the definition and connotation of EWP, human well-being and ecological consumption are the two key elements in constructing EWP.

Human well-being is a multidimensional concept that encompasses citizens' needs and fulfillment in all aspects of their lives. Currently, human well-being is mostly assessed at the national level and can be broadly categorized into objective, subjective, and comprehensive well-being. The most widely recognized measure of objective well-being is the United Nations Development Program's (hereafter UNDP) Human Development Index (hereafter HDI), which measures objective well-being in three dimensions: health (level of health and medical care), education (level of educational attainment), and income distribution (ability to lead a decent life). UNDP has been publishing the Inequality-adjusted Human Development Index (hereafter IHDI) since 2010. The IHDI takes into account the unequal distribution of the three dimensions of objective well-being among the population and is equivalent to a "discounted" HDI [9]. Then, the "Easterlin Paradox" brought the importance of subjective well-being research to the forefront [10]. Measuring subjective well-being is usually done by collecting self-reported data from individuals to assess how satisfied and happy they are with their lives. Common indicators are Life Satisfaction (hereafter LS) and Happiness Index (hereafter HI) [11]. However, quantification of subjective well-being is difficult to analyze in cross-sectional comparisons due to differences in individual subjective perceptions and traditional cultures in different regions [12]. Comprehensive well-being is the combination of subjective and objective well-being. Zhang & Zhu [13] measured comprehensive well-being by the product of IHDI and LS and named it the Happy and Equal Human Development Index (hereafter HE-HDI). Recently, the Organization for Economic Co-operation and Development (OECD) has proposed a composite index reflecting people's living standards and quality of life, known as the Better Life Index (BLI) [14]. The index covers 38 OECD countries and contains 11 indicators. It assigns weights (0–10) through individual preferences for different indicators of well-being, which are weighted and averaged to obtain the BLI for each country. However, this method of assessing well-being through simple weighting has been questioned by some scholars. Costanza et al. [15] argued that weighted averaging fails to reflect the importance of indicators to different country pairs of preferences, and also fails to explain the intrinsic correlation between indicators. Therefore, referring to Zhang & Zhu [13], this paper applies a composite measure of human well-being based on the product of subjective and objective well-being at the country level. Differently, the product of HDI and LS is chosen to characterize human well-being.

According to the choice of ecological consumption indicators, the Ecological Footprint (EF) is the most reliable and complete indicator available in existing research. The EF calculates the depletion of natural resources and emissions of wastes on the consumption side of human productive activities in both the source and sink dimensions. Specifically, EF is calculated by tracking the use of biologically productive surface areas where humans meet their needs and absorb waste. Typically, these areas are cropland, pasture, fishing grounds, building land, forest area, and land carbon demand. Because of its comprehensiveness, the EF can capture the impacts of human demand on ecosystems, either directly or indirectly [16,17]. Therefore, EF is selected as an indicator to measure ecological consumption in this paper. Based on the selected human well-being indicators (HDI × LS) and ecological consumption indicators (EF), this paper constructs an Index of Ecological Well-being Performance (hereafter IEWP) and incorporates it into an empirical analysis to explore how human inequality, urbanization, and the interaction term affects EWP.

It is crucial to understand the drivers of EWP to improve the efficiency with which ecological consumption is translated into human well-being. Human inequality and urbanization are socio-economic phenomena that cannot be ignored in the contemporary world and have potential implications for enhancing EWP. Human inequality is an integrated systemic inequality that encompasses not only economic inequality but also social inequality. The structural upheavals that accompany economic growth exacerbate differences and inequalities. In this context, inequality is more likely to widen the gap between rich and poor and an imbalance of opportunities, which may lead to a breakdown in social cohesion. Drawing on Human Development Reports [18], we examined inequality in human development across three dimensions: income distribution, education, and health. Existing literature mostly discusses the relationship between income inequality and the ecological environment, implying the impact of inequality on ecological sustainability. For example, rising inequality leads to a surge in energy consumption and increased environmental emissions [19–21]. Among them, the level of per capita income is a key driver of carbon emissions [22,23]. On the other hand, some literature also confirms that economic and social inequality is strongly linked to public health and well-being [24,25]. Overall, these findings imply the potential impact of human inequality on EWP enhancement.

It is well known that urbanization is showing an accelerating trend globally. The realization of sustainable development globally depends largely on cities [22]. As engines of socio-economic development, cities have become the center of environmental problems while improving the well-being of their inhabitants. Existing literature on the impact of urbanization on EWP is not yet clear. Some scholars proved that urban planning is conducive to improving the quality of cities and residents' well-being [26], while urbanization has an improvement effect on air and environmental quality [27–29]. However, with increasing urban populations, urban development is not only urban ecology but may also reduce economic and social well-being. For instance, Wei et al. [30] concluded that urban land expansion creates spatial concentration and inequality problems, which exacerbates the economic development gap between cities. Andrei et al. [31] argued that the pollution problem in cities affects the economic and social development of urban areas, which in turn reduces the willingness of the urban population to live in the city. The above findings reflect the important role of urbanization in improving EWP from the side. Therefore, this paper empirically analyzes the impact of urbanization on EWP by using the most widely known indicator for measuring urbanization, which is the urban population (% of the total population).

This paper aims to enrich the study of EWP and its influencing factors by exploring how human inequality, urbanization, and the interaction between the two factors affect EWP from both theoretical and empirical perspectives. Employing panel data for 129 countries over the period from 2010 to 2021, this study applies the System Generalized Method of Moments (System-GMM) model to explore the effects of human inequality, urbanization, and the interaction term on EWP.

The potential contributions of this study are as follows. First, most of the existing studies statically measure EWP with a comprehensive system of multiple input-output indicators [5,8,32,33], ignoring the core connotation of EWP. In this paper, three widely recognized indicators, namely, HDI, LS, and EF, are selected to construct IEWP using the ratio method, to dynamically assess the national EWP. Second, the majority of studies focus on the impact of economic inequality on ecological consumption or well-being separately [19,20,23–25]. This study utilizes the coefficient of human inequality, combining the three dimensions of human inequality, income, education, and health, to answer the effect of comprehensive human inequality on EWP. This can delve deeper into the impact of human inequality on the conversion of ecological consumption into well-being. Finally, this paper empirically analyzes using the dynamic panel model — the System-GMM to verify whether there is a dynamic cumulative effect on EWP.

The remainder of the study is structured as follows. Section 2 presents the literature review and theoretical foundation. Section 3 addresses the methodology and data. Section 4 presents the empirical results. Section 5 conducts the discussion, and conclusions are provided in Section 6.

2. Literature review and theoretical foundation

Exploring the drivers affecting EWP is essential for improving the efficiency of translating ecological consumption into human well-being. Currently, human inequality and urbanization are two pervasive and profound economic and social phenomena globally with potential impacts on improving EWP. Based on this, this section explores the impacts of human inequality, urbanization, and the interaction term on EWP at a theoretical level.

2.1. Human inequality and EWP

Human inequality is a root cause of polarization and poverty, hindering economic development and social stability [33]. Throughout global economic history, sustained economic growth has exacerbated global and national inequality, mainly in the form of widening income gaps between and within countries [34,35] However, as time evolves, not only does income inequality exist between countries, but social inequality has also increased. Hwang [36] argued that inequality of opportunity, such as education and employment, is more likely to be overlooked compared to inequality of outcome in income and wealth. Therefore, this paper explores comprehensive human inequality that encompasses not only economic income inequality but also social inequality such as education and health.

Most of the existing literature discusses the relationship between income inequality and ecological consumption or well-being, implying the potential impact of inequality on EWP. Hou et al. [37] analyzed the relationship between income inequality, economic growth, and carbon footprints using a sample of 43 major economies during 1995–2019. Their results showed that lower Gini coefficients, meaning a more equitable distribution of income, significantly contribute to carbon emission reductions. Similarly, Policardo & Sanchez Carrera [38] found that increased economic inequality in terms of income or wealth inhibits sustainable economic growth. Zhang et al. [39] analyzed the impact of educational inequality and crime in 288 cities in China. Their study indicated that educational inequality reflects social polarization and significantly increases the incidence of crime. This is not conducive to promoting social equity and improving well-being. Robson et al. [40] explored income-related health inequalities by collecting data among UK adults. The findings suggested that health importance is associated with income class and that the importance attached to the health of the poor is weak. Lower incomes lead to worse health. Acheampong et al. [41] applied the Gini index to characterize income inequality and analyze the impact of income inequality on access to safe drinking water, sanitation and hygiene (WASH) in 119 countries over the period 2004–2020. The study found that income inequality hinders the population's access to hygiene knowledge and inhibits improvements in well-being. Meanwhile, Acheampong et al. [42] examined the impact of income inequality and redistribution on energy consumption in 166 countries. Their study emphasized that income inequality increases energy consumption and depletes non-renewable resources. Sun et al. [43] studied the impact of income inequality on the environment in N-11 countries. The findings showed that income inequality increases social disparities and has a dampening effect on ecological sustainability. Husaini et al. [44] using panel data for 10 natural resource-rich countries in Asia from 1996 to 2020, confirmed that high dependence on natural resources increases income inequality. In addition, some studies argued that rising inequality leads to increased energy consumption and environmental emissions [19–21].

Building on previous research, this paper incorporates the combined income, education, and health dimensions of inequality to revisit the relationship between human inequality and EWP. Widening or exacerbating human inequality not only carries the risk of increased ecological consumption but may also reduce well-being gains. This would lead to inefficient translation of ecological consumption into human well-being, thereby hindering the enhancement of EWP. Therefore, we propose the following hypothesis.

Hypothesis 1. Human inequality has an inhibitory effect on increases in EWP.

2.2. Urbanization and EWP

Cities have been the engines of socio-economic development since the industrial revolution. Accompanied by the agglomeration of the urban population, urbanization has become an inevitable result of economic and social development and is also closely related to human well-being and ecological sustainability. Urbanization represents the process of population concentration in cities. This process includes not only the continuous expansion of population size but also economic development, industrial structure transformation, and other aspects. There is no doubt that urbanization brings economic and social benefits and improves people's quality of life.

Some scholars confirm that the promotion of urbanization is conducive to ecological transformation and well-being enhancement. Zhang et al. [45] explored the dynamic relationship between urbanization and EWP with the urban agglomeration in the middle reaches of the Yangtze River. It was found that promoting urbanization can significantly strengthen EWP. Yang et al. [46] empirically highlighted that urbanization significantly contributes to the area covered by vegetation and also promotes the increase of arable land area pairs by using remote sensing and demographic data from 2000 to 2020. Pan et al. [47] investigated the relationship between urbanization and green development of cities by using China's Yangtze River Economic Belt. The results showed that rapid urbanization brings great ecological pressure to urban development in the early stage, but significantly promotes urban green development in the later stage. Xu et al. [48] studied the impacts of 115 cities on carbon emissions in China from 2011 to 2018. Their study confirmed that urbanization significantly promotes urban carbon emission reduction, which is conducive to low-carbon sustainable urban development.

However, some scholars argue that urbanization reduces the level of ecological sustainability and well-being. Liu et al. [29] confirmed that urbanization exacerbates environmental degradation with data from five different economies covering 1990 to 2020. Gilman & Wu [49] analyzed that urban population growth and land use expansion limit water availability using a sample of the Phoenix metropolitan area in the United States. They concluded that urbanization based on borrowed water resources is unsustainable. Zhang et al. [50] used 2012–2017 Chinese urban data to study the impact of urbanization on carbon emission spillover. The study revealed that urbanization has a significant cross-regional carbon spillover effect and hinders low-carbon socio-economic transformation.

Reviewing the above literature, we find that the relationship between urbanization and EWP has not yet been determined, with both positive and negative views. Essentially, urbanization can realize the recycling of ecological resources through technical means, thus reducing ecological consumption and improving ecological utilization efficiency. Meanwhile, the urban ecological environment provides residents with good living conditions and enhances their sense of well-being. As mentioned above, urbanization is conducive to the efficient conversion of ecological consumption into human well-being, thereby increasing the efficiency of conversion and thus enhancing EWP.

Hypothesis 2. Urbanization exerts a positive influence on enhancing EWP.

2.3. The interaction of human inequality and urbanization on EWP

Human inequality is a universal phenomenon of economic and social development, while urbanization is an inevitable consequence of economic and social development. The two are interlinked in promoting sustainable development and may affect EWP. On one hand, while urbanization drives EWP, increasing human inequality can undermine the positive effects of urbanization and stimulate ecological depletion. Gao et al. [51] analyzed the link between renewable energy and urbanization for different income groups. Their study found that for low- and middle-income countries, renewable energy has an inhibitory effect on urbanization; conversely, renewable energy has a facilitating effect in high-income countries. Aguilar & Hernandez-Lozano [52] found that rising inequality leads to increased social marginalization in metropolitan areas, using a sample of Latin America and Mexico.

On the other hand, the rapid advancement of urbanization may lead to the overexploitation of urban resources, which in turn exacerbates economic and social inequality. Guo et al. [53] investigated the phenomenon of social inequality in Chinese cities. The findings suggested that the advancement of urbanization has resulted in severe social inequality and segregation. Lynam et al. [54] emphasized that urbanization has exacerbated socio-spatial immobility, leading to unequal socio-spatial development. Ekeocha et al. [55] explored the relationship between urbanization and inequality by using data from African countries between 1996 and 2014. Their study confirmed that high population density pressure forces low urban space to be contested, which in turn hinders unsustainable urbanization. Wu et al. [56] examined the issue of urban spatial provision and inequality in 67 cities in China. The study revealed that there is a lack of spatial supply in first-tier cities and a high degree of inequality in rapidly developing second-tier cities.

Guo & Li [57] explored the issue of urban-rural educational inequality in China and found that large-scale population migration driven by rapid urbanization is the main cause of educational inequality.

In light of the discussion in the existing literature, we assume that higher human inequality weakens the positive effect of urbanization to a certain extent; meanwhile, the advancement of urbanization strengthens the inhibitory effect of human inequality. Therefore, this paper hypothesizes that the interaction between human inequality and urbanization further depresses EWP. Hence, Hypothesis 3 is proposed.

Hypothesis 3. The interaction between human inequality and urbanization has an inhibitory effect on EWP.

3. Methodology and data

In this section, we detail data selection and provide source websites for all datasets. Next is the research design. After discussing the model estimation methods, a rational econometric model is constructed.

3.1. Data

This paper applies annual unbalanced panel data covering 129 countries around the world from 2010 to 2021. The length of the time frame of the study depends entirely on the availability of data. We exclude severely missing data. Also, to avoid the interference of extreme outliers, the data in this paper are shrink-tailed by 1 %. Next, we describe the study variables in detail.

3.1.1. Measuring EWP

Drawing on the discussion above, the human well-being indicator (HDI × LS) and the ecological consumption indicator (EF) are selected in this paper to construct the IEWP. It is worth noting that there is a diminishing marginal utility in the value of EWP due to the relative relationship between human well-being and ecological consumption. If the ratio of human well-being to ecological consumption is used directly to estimate EWP, this can be biased [58]. According to Zhang and Zhu [13], we take the natural logarithm of the EF as the denominator to ensure that the ratio fluctuates proportionally. Particularly, to avoid negative values after taking logarithms, Ln(1+EF) is employed. As such, this paper constructs IEWP as shown below.

$$IEWP = = \frac{HDI \times LS}{Ln(1 + EF)} \tag{1}$$

3.1.2. Main explanatory variables

In this paper, Human inequality and urbanization are vital independent variables. The coefficient of human inequality (CHI) is used as a proxy for human inequality and is obtained from the Human Development Report, proposed by UNDP. Specifically, CHI is an unweighted average of inequalities in health, education, and income. Employing CHI reflects systemic inequalities, which encompass not only economic inequality but also social inequality [59]. The magnitude of CHI values represents the degree of inequality in the economy and society. Larger CHI values indicate higher human inequality.

The degree of urbanization is related to the population of urban dwellers [60]. This paper emphasizes the effects of urbanization from the perspective of population agglomeration. Referring to previous studies [16,61], urban population (URB) is employed to quantify urbanization, reflecting the structural characteristics of urban and rural populations. URB is calculated as the percentage of urban residents in the overall population. As global urbanization progresses, there is a growing number of people living in urban zones and clustering in central cities.

3.1.3. Control variables

The essence of EWP is people-oriented sustainable development, which is to realize the win-win outcome of minimizing ecological consumption and optimizing socio-economic well-being. We thus select the following control variables in terms of economic, social, and environmental aspects to consider other factors affecting EWP.

At the economic level, economic growth is the primary control factor to be considered. Given the close link with EWP, this paper employs the logarithm of economic growth and its squared term to test the Environmental Kuznets Curve (EKC) hypothesis. Economic growth is measured employing GDP per capita (GDPPC), which reflects a country's production outcomes. Trade openness (TO), as an essential part of open economic development, indicates the degree of external dependence on a country's economy. It is measured using the summation of cumulative imports and exports percentage of GDP. Consumption demand (CD) is a final demand that represents the country's needs for material, cultural and spiritual life. It is expressed in terms of final consumption expenditure, which is the sum of household final consumption expenditure (private consumption) and general government final consumption expenditure (general government consumption). Reasonable consumer expenditure can enhance people's living standards. In contrast, it leads to environmental pollution and increases the carbon footprint [62,63].

Gender balance (GB), as an important parameter at the social level, is one of the goals for achieving sustainable development and reflects the differences in the proportion of males and females in society. Gender imbalance in life and work reduces well-being and jeopardizes health [64]. This paper calculates the absolute value of females (% of total population) minus 50 % to measure GB.

Biocapacity (BIO) is employed in ecosystem accounting as a control variable at the environmental level. According to the Global Footprint Network, BIO, also known as the Earth's renewable capacity, is measured by counting the amount of biologically productive land and sea area. It possesses resource-producing and waste-absorbing capacity, reflecting ecological sustainability [65,66]. The BIO and EF belong to the relationship between sources and sinks in ecosystems. The EF is the demand of the ecosystem, while BIO is the supply of the ecosystem. The difference between the two can indicate the state of the ecosystem. When BIO exceeds EF, there is an "ecological surplus", indicating that human demand is within ecological capacity. Conversely, when BIO is less than EF, the ecosystem is in an "ecological deficit", indicating that human demand will exceed ecological limits, which means that the sustainability of the ecosystem will be jeopardized.

3.1.4. Data sources and descriptive statistics

The Human Development Report of the UNDP provided data on HDI from 1990 to 2021 and CHI from 2010 to 2021, covering 195 countries. (The website is https://hdr.undp.org/data-center/human-development-index, accessed on 24 August 2023). Data for LS were obtained from the World Happiness Report 2023 spanning from 2005 to 2022. (The website is https://worldhappiness.report/ed/2023/#read, accessed on 24 August 2023). Data for EF and BIO were provided by the National Footprint and Biocapacity Accounts (NFBAs), respectively, from the Global Footprint Network (2023 Edition). (The website is https://www.footprintnetwork.org/, accessed on 24 August 2023). The dataset contains more than 200 countries worldwide from 1961 to 2022. The data for URB, GDPPC, TO, CD, and GB were obtained from the World Bank database (The website is https://data.worldbank.org/indicator, accessed on 5 September 2023). Based on the above data matching results, the final sample contained unbalanced panel data for 129 major countries around the globe from 2010 to 2021.

Table 1 details the descriptive statistics for the main variables. Each variable is well observed and distributed differently. In terms of the explanatory variables, the mean, minimum, and maximum values of EWP are 3.276, 1.584, and 6.909 respectively for the full sample. This indicates that most of the countries in the sample have low levels of EWP. Fig. 1 illustrates the variation in the IEWP values of the countries during the sample period. We can see that the overall trend of IEWP is increasing. This indicates that countries are gradually focusing on the relationship between IEWP and human well-being. For emerging and developing countries, the IEWP values are higher than those of developed countries, but the values fluctuate more. The IEWP values of developed countries are increasing with a steady trend every year. IEWP values for developed and emerging and developing countries are equal after 2018. Statistical data on human inequality and urbanization show large variations within the sample and between countries. Additionally, the mean value of GB is 0.957, the minimum value is 0.016, and the maximum value is 4.185, indicating that there is a serious gender imbalance in the countries. The mean value of BIO is 2.868 while the maximum value is 16.254, implying that ecological self-resilience is low and ecological overshoot may exist in some countries.

3.2. Empirical models

Indeed, it is not possible to accurately predict in advance the exact efficiency with which ecological consumption will be transformed into well-being. However, the impact of ecological consumption and well-being on a given country and its inhabitants can be correlated with unobserved variables. Also, the existence of an inherent vulnerability in a country is correlated with the likelihood or propensity of the country to be adversely affected by ecology or well-being [67]. Therefore, to address endogenous bias, this study utilizes the System-GMM estimation method extended by Blundell and Bond [68]. The System-GMM approach takes the original level equations and the first-difference equations as a system of equations for two-step estimation [69]. The estimation method corrects the potential bias of the Difference-GMM estimator and effectively utilizes the available time series information, thus improving the estimation efficiency [70,71]. It simultaneously ensures that the estimation is unbiased, convergent, and efficient. Importantly, the estimators of the System-GMM use observations of the explanatory and lagged dependent variable (LDV) as internal instruments to avoid statistical flaws. This means that the EWP is independent of current perturbations but is influenced by the past. That is, EWP values in the previous period tend to influence the one in the subsequent period.

The dynamic panel data model is given by the following equation.

$$IEWP_{it} = \alpha_0 + \alpha_1 IEWP_{it-1} + \alpha_2 CHI_{it} + \alpha_3 URB_{it} + \alpha_4 X_{it} + \delta_i + \eta_t + \varepsilon_{it} \tag{2}$$

where the subscripts i and t represent country and year, respectively. $IEWP_{it}$ standing for the level of EWP in the country i at time t. $IEWP_{it-1}$ is the LDV. CHI is the measure of human inequality, URB denotes urbanization. X_{it} is a vector of economic, social, and environmental control variables (economic growth, trade openness, consumption demand, gender balance, biocapacity). δ_i represents

Table 1
Descriptive statistics of variables.

Abbreviation	Variable	N	Mean	Std.Dev.	Min	Max
IEWP	The Index of Ecological Well-being Performance	1351	3.276	0.815	1.584	6.909
CHI	Coefficient of Human Inequality (%)	1351	17.732	9.588	5.111	39.183
URB	Urbanization (% of total population)	1351	60.539	21.387	16.35	98.001
GDPPC	Gross Domestic Product per Capita, take the logarithm	1331	9.406	1.122	7.044	11.456
TO	Trade Openness (% of GDP)	1308	85.331	52.072	24.685	322.675
CD	Consumption Demand (% of GDP)	1298	79.201	13.061	44.344	113.472
GB	Gender Balance (%)	1351	0.975	0.957	0.016	4.185
BIO	Biocapacity (gha per capita)	1351	2.868	3.539	0.156	16.254

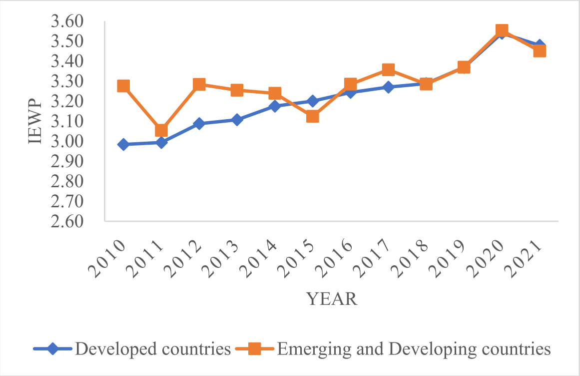

Fig. 1. IEWP from developed and emerging and developing countries during 2010–2021.

unobserved country-specific effects. η_t denotes the time-specific effects capturing common temporal shocks. ε_{it} captures all the omitted factors.

α_2 reflects the direct effect of human inequality on EWP. Hypothesis 1 expects the sign of this estimated coefficient to be negative. In this case, reducing inequality enhances EWP. α_3 represents the coefficient of urbanization, which reflects the direct impact of urbanization on EWP. The sign of α_3 is expected to be positive in Hypothesis 2, implying that increased urbanization is conducive to enhancing EWP.

Indeed, human inequality and urbanization may interact with each other. The interaction term may also affect improving EWP. Nevertheless, whether this interaction term has a positive or negative effect on EWP needs to be further verified. Accordingly, this paper introduces an interaction term between human inequality and urbanization. The specific model is formulated as follows.

$$IEWP_{it} = \beta_0 + \beta_1 CHI_{i,t} + \beta_2 URB_{it} + \beta_3 (CHI_{it} \times URB_{it}) + \beta_4 X_{it} + \delta_i + \eta_t + \varepsilon_{it} \tag{3}$$

$$IEWP_{it} = \beta_0 + \beta_1 CHI_{it} + \beta_2 URB_{it} + \beta_3 (CHI_{it} - \overline{\overline{CHI_{i.}}})(URB_{it} - \overline{URB_{i.}}) + \beta_4 X_{it} + \delta_i + \eta_t + \varepsilon_{it} \tag{4}$$

$$IEWP_{it} = \gamma_0 + \gamma_1 IEWP_{it-1} + \gamma_2 CHI_{it} + \gamma_3 URB_{it} + \gamma_4 (CHI_{it} - \overline{\overline{CHI_{i.}}})(URB_{it} - \overline{URB_{i.}}) + \gamma_5 X_{it} + \delta_i + \eta_t + \varepsilon_{it} \tag{5}$$

where $CHI \times URB$ is an interaction term between these two variables. In Model (3), the interaction term is added. Since the interaction term is highly correlated with the two explanatory variables, it may cause multicollinearity in the model estimation [72,73]. Therefore, Model (4) applies centering to the interaction term, which is subtracting each variable from its mean. Model (5) considers the dynamic effects of EWP and adds the LDV to Model (4).

With respect to γ_4, the coefficient of the interaction term, the positivity or negativity of the sign is uncertain. If $\gamma_4 > 0$, it means that human inequality strengthens the assumed positive effect of urbanization on EWP, and urbanization weakens the hypothesized negative effect of human inequality on EWP. This implies that fostering a positive interaction between human inequality and urbanization is beneficial for enhancing EWP. In contrast, if $\gamma_4 < 0$, it indicates that urbanization exacerbates the negative impact of human inequality on EWP, while human inequality weakens the positive impact of urbanization on EWP. In this context, the paradoxical relationship between human inequality and urbanization further inhibits the enhancement of EWP. That is, Hypothesis 3 holds.

4. Empirical results

In this section, the System-GMM dynamic panel model is applied to assess the impact of human inequality, urbanization, and the interaction term on EWP. The model first runs benchmark regression and analyzes the regression results. Then, this study conducts robustness testing using several techniques to ensure the accuracy of the results.

4.1. Benchmark regression analysis

Before the benchmark regression, this paper applies the Variance Inflation Factor (VIF) test for covariance to ensure the accuracy of the model estimation. The results are reported in Table 2. Through the analysis of covariance, we find that the maximum value of VIF

Table 2
Results of collinearity analysis.

	CHI	URB	GDPPC	TO	CD	GB	BIO
VIF	2.40	2.09	3.09	1.45	1.39	1.22	1.22
1/VIF	0.42	0.48	0.32	0.69	0.72	0.82	0.82

for each variable is 3.09 and the mean value is 1.84, which is much smaller than the critical value of 10. This indicates that the regression model does not have serious multicollinearity problem [74]. That is, the regression analysis of causal relationships between variables can be carried out.

Next, we perform a regression analysis based on the model developed in Section 3.2. Table 3 reports the regression estimates. Columns (1)–(2) are regression analyses for the full sample. We introduce CHI and URB separately and include columns for all control variables. Based on the country classification of World Economic Situation and Prospects 2023 [75], this paper categorizes the sample countries into developed and emerging and developing countries. Columns (3)–(4) present the estimation results for developed countries. Regression results for emerging and developing countries are summarized in columns (5)–(6). The p-values of the Arellano-Bond autocorrelation test indicate that the residual series of the difference equations are only first-order serially correlated and not second-order serially correlated, which satisfies the prerequisites of System-GMM. Meanwhile, the p-values of the Sargan test are greater than 0.1, indicating that all instrumental variables are valid. It proves that there is no over-identification of instrumental variables. The model passes the AR test and the Sargan test, demonstrating that the estimation results of the System-GMM are consistent and reliable.

First, we find that the estimated coefficients on LDV are positive and all are significant at the 1 % level of significance, indicating that there is a noticeable period lag in EWP. An important fact to highlight is that EWP has a cumulative effect, meaning that EWP in the previous period tends to affect the current one. The reason for this is that environmental change is progressive and human systems are dependent on ecological resources for well-being [76]. These factors are dynamically transformed in time and space and require a certain response time [77].

Second, for the full sample, the estimated coefficient of CHI in column (1) is −0.1649, which is significant at the 1 % significance level. This result is consistent with the theoretical expectation of Hypothesis 1. The regression results indicate that human inequality has a significant dampening effect on EWP performance. While the estimated coefficient of URB in column (2) is 0.0390, which is significantly positive at 1 % level of significance. This indicates that urbanization has a significant contribution to EWP performance, validating Hypothesis 2. In this case, the level of EWP increases by 16.49 % for each unit of reduced human inequality, whereas it rises by 3.90 % for each unit of increased urbanization. Improving inequality is more conducive to enhancing EWP than the urbanization process.

Third, we divide the full sample into two categories based on country type. Columns (3) and (5) show the impact of inequality on EWP in developed vs. emerging and developing countries, respectively. The results show that human inequality has a significant negative effect on EWP and that there is heterogeneity in this effect. Compared to developed countries, rising inequality in emerging and developing countries dampens EWP more significantly. Columns (4) and (6) then report how urbanization affects EWP in different country samples, respectively. It can be seen that the estimated coefficients of urbanization are positive in both developed and

Table 3
Estimation results for the full- and sub-sample.

Variable	Full-sample		Developed countries		Emerging and Developing countries	
	(1)	(2)	(3)	(4)	(5)	(6)
L.IEWP	0.3044[c]	0.3441[c]	0.6724[c]	0.5746[c]	0.3095[c]	0.3273[c]
	[0.0083]	[0.0073]	[0.0560]	[0.0698]	[0.0073]	[0.0060]
CHI	−0.1649[c]		−0.0675[c]		−0.1518[c]	
	[0.0174]		[0.0147]		[0.0118]	
URB		0.0390[c]		0.0232		0.0534[c]
		[0.0060]		[0.0336]		[0.0058]
LNGDPPC	−2.7907[c]	−4.3912[c]	1.6932	−8.5072	−5.4118[c]	−8.1835[c]
	[0.6812]	[0.7894]	[2.9394]	[5.3369]	[0.7989]	[0.8749]
$(LNGDPPC)^2$	0.0976[c]	0.2340[c]	−0.0728	0.4220[a]	0.2588[c]	0.4474[c]
	[0.0371]	[0.0422]	[0.1441]	[0.2520]	[0.0443]	[0.0489]
TO	−0.0057[c]	−0.0032[c]	−0.0034[c]	−0.0029[a]	−0.0013[a]	0.0010
	[0.0009]	[0.0009]	[0.0011]	[0.0015]	[0.0007]	[0.0008]
CD	−0.0275[c]	−0.0217[c]	−0.0005	0.0127[c]	−0.0193[c]	−0.0241[c]
	[0.0025]	[0.0035]	[0.0052]	[0.0031]	[0.0023]	[0.0031]
GB	−0.2089[c]	0.1149	0.0144	−0.0088	−0.5132[c]	0.1264[a]
	[0.0825]	[0.0838]	[0.0402]	[0.0725]	[0.0901]	[0.0740]
BIO	−0.1913[b]	−0.3182[c]	−0.0565[c]	−0.0373[b]	−0.1702[c]	−0.4158[c]
	[0.0280]	[0.0060]	[0.0213]	[0.0159]	[0.0234]	[0.0196]
_cons	26.2011[c]	22.9709[c]	−7.4846	41.8983	35.6528[c]	39.1083[c]
	[3.1792]	[3.6209]	[14.8820]	[27.6747]	[3.6463]	[3.9748]
Observations	1120	1120	356	356	764	764
Number of countries	129	129	35	35	94	94
AR(1)	0.0512	0.0461	0.0001	0.0002	0.0646	0.0570
AR(2)	0.1409	0.1538	0.7259	0.8491	0.1327	0.1517
Sargan test	0.4533	0.0497	0.9999	1.0000	0.4204	0.2615

Notes: All regressions are two-step System-GMM. t statistics in parentheses.

[a] $p < 0.10$.

[b] $p < 0.05$.

[c] $p < 0.01$.

emerging and developing countries. However, for developed countries, the boost of urbanization on EWP in emerging and developing countries is more significant.

Fourth, the regression results show that the control variables for the economic, environmental, and social dimensions all have different significant effects on EWP, indicating the necessity and rationality of including control variables in the model. For the full sample, columns (1)–(2) of Table 3 show that the estimated coefficients of LNGDPPC are significantly negative, while the coefficients of its squared term are significantly positive. This indicates that there is a U-shaped relationship between GDP per capita and EWP as the level of economic development increases. Meanwhile, trade openness, consumption, gender balance, and biocapacity are all negatively related to EWP.

To test Hypothesis 3, this paper introduces an interaction term between human inequality and urbanization. The CHI, URB, and CHI × URB are added sequentially in Table 4. It was found that the coefficient of CHI × URB is significantly negative at the 1 % level. This indicates that the interaction term further impacts EWP. Specifically, the marginal effect of human inequality on IEWP is −0.1251-0.0006 CHI, which indicates that human inequality weakens the promotion of urbanization on EWP to some extent. It implies that more inequitable distribution will amplify the negative impacts of urbanization, which in turn is detrimental to the enhancement of EWP. On the contrary, the marginal effect of urbanization on IEWP is 0.0195–0.0006 URB, indicating that urbanization reinforces the negative impact of human inequality on EWP. This implies that the advancement of urbanization may exacerbate human inequality. Thus, human inequality and urbanization are in a contradictory relationship, and their interaction can further inhibit the improvement of EWP. That is, Hypothesis 3 holds.

4.2. Robustness tests

To ensure the reliability of the findings, this section chooses the method of replacing the GDPPC and supplementary government variable for the robustness test.

4.2.1. Robustness check 1: Replacement of GDPPC

Referring to Ref. [59], GDPPC is replaced with GNIPC (gross national income per capita) to re-estimate the benchmark model. The regression results are shown in columns (1) and (3) of Table 5. Compared to Tables 3 and 4, there are differences in the magnitude of the CHI, URB, and CHI × URB regression coefficients, but neither the positive nor negative sign nor the significance changes significantly, indicating that the results of this paper are robust.

4.2.2. Robustness check 2: supplementary variable

The sample scope of this paper is at the country level. Considering the different institutional and political environments between countries, this paper supplements the addition of control variables for policy to demonstrate the robustness of the benchmark

Table 4
Regression results for the full-sample interaction term.

Variable	(1)	(2)	(3)
L.IEWP	0.3044***	0.3403***	0.3517***
	[0.0083]	[0.0044]	[0.0038]
CHI	−0.1649***	−0.1379***	−0.1251***
	[0.0174]	[0.0098]	[0.0026]
URB		0.0274***	0.0195***
		[0.0036]	[0.0010]
CHI × URB			−0.0006***
			[0.0002]
LNGDPPC	−2.7907***	−3.2917***	−1.5588***
	[0.6812]	[0.3802]	[0.4425]
$(\text{LNGDPPC})^2$	0.0976***	0.1183***	0.0307
	[0.0371]	[0.0214]	[0.0238]
TO	−0.0057***	−0.0062***	−0.0067***
	[0.0009]	[0.0005]	[0.0003]
CD	−0.0275***	−0.0308***	−0.0327***
	[0.0025]	[0.0012]	[0.0007]
GB	−0.2089***	−0.082**	−0.0842***
	[0.0825]	[0.0408]	[0.0213]
BIO	−0.1913***	−0.2380***	−0.2214***
	[0.0280]	[0.0224]	[0.0054]
_cons	26.2011***	27.1128***	18.8825***
	[3.1792]	[1.7711]	[2.0429]
Observations	1120	1120	1120
Number of countries	129	129	129
AR(1)	0.0512	0.0543	0.0506
AR(2)	0.1409	0.1463	0.1482
Sargan test	0.4533	0.3622	0.6148

Notes: All regressions are two-step System-GMM. t statistics in parentheses. $^*p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$

Table 5
Robustness tests.

Variable	Replacement of GDPPC			Supplementary variable		
	(1)	(2)	(3)	(4)	(5)	(6)
L.IEWP	0.3002***	0.3429***	0.3537***	0.3056***	0.3463***	0.3506***
	[0.0083]	[0.0073]	[0.0039]	[0.0085]	[0.0077]	[0.0042]
CHI	−0.1680***		−0.1287***	−0.1640***		−0.1241***
	[0.0180]		[0.0026]	[0.0172]		[0.0032]
URB		0.0398***	0.0199***		0.0367***	0.0204***
		[0.0057]	[0.0010]		[0.0062]	[0.0011]
CHI × URB			−0.0005***			−0.0007***
			[0.0002]			[0.0002]
LNGNIPC	−3.1858***	−4.7908***	−2.0888***			
	[0.6953]	[0.7443]	[0.4569]			
(LNGNIPC)^2	0.1162***	0.2556***	0.0579****			
	[0.0374]	[0.0401]	[0.0245]			
LNGDPPC				−2.7487***	−4.5974***	−1.4167***
				[0.6769]	[0.7624]	[0.4356]
(LNGDPPC)^2				0.0957***	0.2445***	0.0238
				[0.0369]	[0.0409]	[0.0236]
TO	−0.0058***	−0.0034***	−0.0068***	−0.0057***	−0.0035***	−0.0063***
	[0.0009]	[0.0009]	[0.0003]	[0.0009]	[0.0009]	[0.0003]
CD	−0.0279***	−0.0220***	−0.0325***	−0.0273***	−0.0224***	−0.0325***
	[0.0025]	[0.0034]	[0.0008]	[0.0025]	[0.0034]	[0.0007]
GB	−0.2494***	0.1097	−0.0956***	−0.2081****	−0.0977	−0.0746***
	[0.0806]	[0.0851]	[0.0232]	[0.0822]	[0.0846]	[0.0196]
BIO	−0.1950***	−0.3237***	−0.2248***	−0.1927***	−0.3187***	−0.2200***
	[0.0281]	[0.0302]	[0.0053]	[0.0282]	[0.0316]	[0.0061]
PS				0.0145	0.1437***	−0.0617***
				[0.0339]	[0.0372]	[0.0102]
_cons	28.4027***	24.8046***	21.4585***	25.9456***	24.2400***	18.0192***
	[3.3359]	[3.4196]	[2.1226]	[3.1518]	[3.4678]	[1.9878]
Observations	1120	1120	1120	1120	1120	1120
Number of countries	129	129	129	129	129	129
AR(1)	0.0538	0.0458	0.0506	0.0511	0.0460	0.0491
AR(2)	0.1383	0.1527	0.1468	0.1413	0.1558	0.1471
Sargan test	0.4438	0.0627	0.6414	0.4472	0.0380	0.6231

Notes: All regressions are two-step System-GMM. t statistics in parentheses. $*p<0.10$, $**p<0.05$, $***p<0.01$.

regression [78]. This paper uses policy stability to characterize government capacity. The specific results are reported in columns (4)–(6) of Table 5. It can be seen that the estimated coefficients of CHI, URB, and CHI × URB are still significant at the 1 % level, and the plus and minus signs are consistent with the benchmark regression results. This again indicates the robustness of the regression results and the reliability of the conclusions.

5. Discussion

In this study, three widely used indicators, namely HDI, LS, and EF, are selected to construct the IEWP. Meanwhile, based on the country level, this paper applies the System-GMM model to empirically examine the impacts of human inequality and urbanization on the EWP in 129 countries from 2010 to 2021. Combined with the regression results above, we explain the empirical results and their research implications in more detail in this section.

First, our data results show that human inequality leads to a decrease in EWP. This means that human inequality is one of the main factors inhibiting EWP. These results are compatible with some papers in the literature, such as [79–81]. The likely reason for this is that inequality in wealth, socioeconomic status, or educational attainment is strongly correlated with people's health and well-being [43,80]. Increased inequality not only leads to a prevalent economic contraction but also increases healthcare costs, which in turn reduces well-being [24,38]. Another valid reason is that the uneven distribution of economic and social resources has led to significant stratification among groups, which is likely to result in a tendency for the underclass to prefer unsustainable ways of meeting their needs. For example, they are more concerned with material issues and do not consider the ecological consumption of goods or services. Interestingly, Chen et al. [25] and Wang and Yuan [81], using a sample of Chinese cities, confirmed that the level of inequality is a key factor influencing environmental degradation and subjective quality of life. The study found that the affluent groups have a greater demand for energy-intensive goods and services, which may generate more carbon emissions. However, the pressure of environmental degradation caused by carbon emissions is largely borne by low-income groups. Thus, human inequality is not only a social problem but also reduces the efficiency of transforming ecological consumption into human well-being, thereby constraining EWP. It follows that mitigating systemic inequality to achieve efficient conversion of ecological consumption into human well-being is necessary.

Second, we confirm that the effect of urbanization on EWP is significantly positive. This means that urbanization has an enhancing effect on EWP. Our findings are consistent with some papers in the literature, such as [82–84]. Urbanization concentrates population and economic activities, leading to a more concentrated and optimized distribution of resources, thus facilitating ecologically efficient use and conservation. Rational urban planning and management can improve environmental quality by protecting ecosystems, promoting the use of renewable energy, and reducing pollution emissions [82]. It is undeniable that cities, as economic centers, attract investment and entrepreneurial activities and provide more employment opportunities. This contributes to the improvement of the economic status and living conditions of the residents [85]. Likewise, better educational institutions and medical facilities in cities can provide better services and opportunities to enhance the quality of life and well-being. Notably, we highlight that urbanization is crucial for EWP, but attention should also be paid to rational planning and management to maximize its positive impacts on enhancing EWP.

Third, we conduct sub-sample regressions based on country type and find heterogeneity in the effects of inequality and urbanization on EWP across countries. Compared to developed countries, the negative impact of human inequality and the positive impact of urbanization are more significant in emerging and developing countries. This result is also supported by Refs. [86,78]. One reason for this may lie in the higher level of technology in developed countries, which helps them to utilize ecological resources more efficiently, which translates into higher human well-being [87]. In contrast, emerging and developing countries may still be struggling to improve resource utilization and technology levels. Next, urbanization in developed countries tends to have high-quality infrastructure and better urban planning [88]. In these countries, the positive effects of urbanization may be relatively small. However, urbanization in emerging and developing countries may still be in its infancy, and urban quality and infrastructure still need to be upgraded, which may result in the positive effects of urbanization being more pronounced in these countries. Moreover, resource rents in emerging and developing countries are increasing their vulnerability compared to developed countries, which also makes EWP in these countries more vulnerable to inequality and urbanization [89].

Fourth, we conclude that the interaction of human inequality and urbanization further affects EWP. This impact, taken as a whole, acts as a disincentive to enhance EWP. Specifically, human inequality weakens the driving effect of urbanization on EWP, while urbanization exacerbates the negative impact of inequality on EWP. This result confirms that human inequality and urbanization are at odds with each other and that their interactions further impede the efficiency with which ecological consumption can be transformed into human well-being, thereby inhibiting EWP. As mentioned by Ref. [90], inequality becomes a feature of urbanization as the level of urban development and population size increases. For example, inequality in the supply as well as the availability of urban infrastructure increases. This finding is supported by Ref. [91], suggesting that accelerated urbanization may lead to increased inequality within countries. While the process of urbanization raises living standards, it also exposes the overuse of urban ecological resources and increases inequality. On the other hand, urbanization promotes land utilization, waste generation, and greater resource consumption. In the pursuit of economic growth and attracting foreign investment, urbanization may sacrifice ecological protection and the welfare of the underclass [92]. In this case, inequality may widen and thus offset or even outweigh the well-being of urbanization. Similarly, advancing urbanization will exacerbate the negative impact of inequality on EWP. This result implies that human inequality and urbanization interact with each other and are critical for enhancing EWP.

Fifth, the validity of the EKC hypothesis is confirmed between GDPPC and EWP. In this context, this result is similar to some studies in the literature, such as [93,94]. Moreover, trade openness and consumption inhibit the increase in EWP. The main reason for this is that trade openness and consumption contribute significantly to natural resource depletion and waste emissions, which in turn cause irreversible harm to ecological sustainability and human health [95,96]. In particular, international trade has transboundary effects that can directly or indirectly transfer resource emissions between income groups in different countries, affecting the quality of life of residents [97].

Sixth, our findings suggest that gender equality has an inhibitory effect on EWP over the study period. This result is contrary to some findings in the literature. For example, Orazalin and Baydauletov [98] found that gender diversity on the board of directors is positively associated with environmental and social performance by investigating listed companies. Elmagrhi et al. [99] and Xia et al. [100] also support that gender diversity has a positive impact on promoting ecological sustainability and well-being. The explanation for our finding contrary to these arguments may lie in the fact that this paper is based on a sample of countries that, as a whole have significant gender imbalances at this stage. Due to the accumulation of gender inequality, social injustice may be triggered and have serious impacts on human health and well-being [101]. Therefore, policy authorities should eliminate gender discrimination and empower women to ensure gender equality, thereby contributing to EWP.

Finally, we estimate that the effect of biocapacity on EWP is significantly negative. That is, the expansion of biocapacity reduces EWP. The results of this study are supported by Refs. [27,102]. Some countries with high biocapacity, such as Australia and Canada, are rich in natural resources. This makes them somewhat dependent on the utilization of natural resources, which leads to an underestimation of ecological sustainability. Moreover, biocapacity exerts upward pressure on the ecological footprint, which in turn stimulates an increase in ecological consumption. Therefore, in the long run, we emphasize that focusing on maintaining ecological carrying capacity is essential for sustainability and well-being enhancement.

6. Conclusions

This study seeks to answer the question of whether human inequality and urbanization are the main factors affecting EWP enhancement. To this end, we construct IEWP using three widely used indicators, namely HDI, LS, and EF. Then, based on unbalanced panel data from 129 countries during 2010–2021, this paper applies the System-GMM model to empirically analyze the effects of human inequality, urbanization, and interaction terms on EWP. Meanwhile, it considers GDPPC, trade openness, consumption, gender equality, and biocapacity as control variables of the model.

The estimation results confirm that EWP has a cumulative effect in the long run. We find that rising human inequality dampens

EWP, while urbanization has an enhancing effect on EWP. It is worth noting that there is heterogeneity in the effects of inequality and urbanization on EWP across countries. Compared to developed countries, the negative impact of human inequality and the positive impact of urbanization are more significant in emerging and developing countries. This study further finds that the interaction of human inequality and urbanization significantly inhibits the enhancement of EWP. In terms of control variables, economic growth has a U-shaped curve relationship with EWP, showing evidence of the EKC hypothesis. Biological carrying capacity has the largest negative effect on EWP, followed by gender equality, consumption, and trade openness. In this study, the benchmark regression was tested for robustness and the analysis confirmed the validity of the model and the reliability of the results.

Based on these findings, we provide the following policy recommendations for policymakers and relevant researchers. First, our study advocates a system-wide approach to reducing human inequality. Policy authorities should implement inclusive policies to ensure the rational distribution of wealth resources and give residents fair education and health protection, recognizing the important impacts of mitigating inequality on ecological well-being. Second, our study highlights that urbanization is crucial for EWP enhancement, especially in emerging and developing countries. Governments must focus on urban planning and quality management to maximize the positive effects of sustainable urbanization. Third, policy authorities should recognize the interplay of both human inequality and urbanization when formulating sustainable development strategies. It is important to pay attention to social equity in the urbanization process to avoid inequality issues that further exacerbate negative environmental impacts. For instance, ensuring a fair distribution of public resources and environmentally friendly attitudes in urban communities. Special attention should be paid to vulnerable groups to provide them with equal access to opportunities and health services. Fourth, policymakers should actively promote policy reforms related to gender balance and the empowerment of women. Lastly, government should increase its efforts to protect natural resources, as the maintenance of biocapacity is crucial to long-term sustainable development.

As with other studies, the current study has some limitations. First, the analysis is limited to a non-balanced panel dataset encompassing 129 countries from 2010 to 2021 due to data availability. Future research could incorporate additional factors and analyze different countries, regions, and social groups. Second, this study primarily focuses on the impact of population-level urbanization on EWP. However, urbanization is a multidimensional concept. In future research, we may consider economic urbanization, land urbanization, and social urbanization factors in addition to population urbanization, and discuss the impact of urbanization structure on ecological welfare. Third, this study utilizes dynamic panel estimation to assess the relationship between human inequality, urbanization, and EWP, thus validating their interrelationships. Nevertheless, further research is needed to explore whether there are structural changes among these variables. Future studies could employ the threshold panel regression model to comprehensively investigate the nonlinear relationship between human inequality, urbanization, and EWP.

Data availability statement

All data and materials are authentic and reliably obtained and will be made available on request.

CRediT authorship contribution statement

Liuliu Lai: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Shuai Zhang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Lilian Li:** Software, Formal analysis, Data curation. **Dajian Zhu:** Validation, Supervision, Project administration, Conceptualization.

Declaration of competing interest

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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