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Measuring Sustainable Development of Baltic States Based on Ecological Footprint

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ABSTRACT

This study assesses the sustainability of the Baltic States—Estonia, Latvia, and Lithuania—by analyzing trends in ecological footprint and biocapacity from 1992 to 2022 using data from the Global Footprint Network. The ecological footprint measures the demand placed on ecosystems by human consumption, while biocapacity reflects the ability of ecosystems to regenerate resources and absorb waste. The findings reveal significant disparities among the three countries. Estonia maintains the highest biocapacity per capita but also the highest ecological footprint, largely due to its reliance on carbon-intensive oil shale energy. Latvia demonstrates the most balanced sustainability profile, with moderate biocapacity and the lowest ecological footprint, consistently staying within ecological limits. Lithuania, in contrast, faces the greatest sustainability challenges, with the lowest biocapacity and a steadily increasing footprint resulting in a persistent ecological deficit. The paper discusses the underlying drivers of these differences, including land use, energy structures, economic development, and policy approaches. The study concludes that differentiated strategies are required to enhance sustainability in each country, and that ecological footprint and biocapacity are effective indicators for guiding policy and evaluating progress toward sustainable development.

INTRODUCTION

Theoretical background

Ecological footprint can be considered a methodology of evaluating the ecological environment and the sustainable development of a region/state. Such an evaluation showed that the biocapacity of built-up area and cropland is worsening after debris flow disaster, followed by forest land, grazing ground, fishing ground and barren ground. All these are protagonist factors of serious impediment in economic development. Other affected factors after disastrous phenomena are that of ecological deficit, nurturing of an unsustainable development and indirectly degrading the quality of life in densely populated urban contexts, in which the geological disasters are certainly playing a significant impeding factor on the socio-economic development (Yue et al., 2012).

From a macro-economics viewpoint it was also reported in the relevant literature that while GDP and FDI often exacerbate environmental degradation, urbanization and value-added agriculture, forestry, and fishing (FAFGDP) improve sustainability in some provinces of China. It is also concluded that China's legal and regulatory frameworks may inadequately mitigate FDI's adverse environmental effects, making a necessity the revision of FDI policies in order to incentivize environmentally friendly practices (Güler et al., 2025).

Another set of valuing ecological footprint within the context of sustainable development is related to the environmental degradation, which is predominately observed when achieving economic growth. This environmental degradation is conceived despite concurring potential mitigating effects of technological advancements and cleaner energy sources (Boukhelkhal, 2022; Hong et al., 2024). In this context it has been literature challenging to investigate the critical impact of cleaner energy sources, advanced technology firms, and economic expansion, especially in the period 2010 - 2022. It was noteworthy that the joint comparison between E7 (emerging seven) and G7 (Group of Seven) economies, support researchers to delineate how these factors collectively influence environmental sustainability in developing and developed countries/emerging economies (lian, 2024). A common target of all developed and developing countries is to enact environmental regulations in order to achieve sustainable development and ecological sustainability. However, no environmental sustainability guarantee is assured if environmental regulations are ineffectively implemented (Ahmed et al., 2022). Another critical determinant is the political institutions that play a key role in the formulation, issuing and monitoring the implementation of environmental regulations. Therefore, it is challenging research to focus on the interrelations developed among democracy, environmental regulations, economic growth and ecological footprint (EF) in long-run study containing the panel of G7 nations in the period 1985 - 2017 (Ahmed et al., 2022).

Among the developing countries it can be denoted the study of Olowu et al. (2018) who empirically investigated the bridging of financial development, sustainable economic opportunity and ecological footprint in Southern African Development Community (SADC) countries (Olowu et al., 2018). Similarly, G-11 countries are experiencing a rapid economic growth with unsustainable ecosystem, subsequently, these countries remain unable to cope with the devastating environmental degradation, making an imperative need of better understanding the effects of eco-innovations (ECO), sub-indices of globalization, economic growth (GDP), and urbanization (URB) on ecological footprints (EF) (Mehmood, 2024).

In the African continent it can be also referred the case of Nigeria, where the national economy is primary relying on the following two major sectors which are considered as emission-induced sectors: petroleum and agricultural sector. Both sectors can be characterized by the over-exploitation of non-renewable sources of energy in energy-fed operations (Udemba, 2020). Therefore, the mitigation of Nigerian economic performance and ecological footprint with other selected variables support country to contribute to the global principle of reducing global warming amidst competitive economic operations (Udemba, 2020). The author of this study further proved that from the ARDL regression findings, a positive relation among income (GDP per capita) and the selected independent variables (mainly that of ecological footprint, agriculture, FDI, energy use). It was also noticeable at the negative relationship amid income and population of the country. Of particular interest was the finding of a one-way (Uni-directional) transmission towards ecological footprint that was passed from economic growth (GDP per capita), from energy use, from population, from economic growth to energy use and from population to economic growth (Udemba, 2020).

From a regulatory and normative viewpoint there are already and globally introduced green initiatives to deal with such environmental issues, such as that of the Kyoto Protocol, the Paris Agreement, and the Sustainable Development Goals (SDGs), but it still remains a contentious multiparametric problem (Udemba et al., 2024). Practically emerging economies are unavoidably excluded from such initiative and only few literature studies have been recently devoted to better understand the response of emerging economies toward a sustainable environment, such as that of BRICS economies (Brazil, Russia, India, China and South Africa) (Udemba et al., 2024). In this empirical study authors employed representative innovative environmental determinants including real income, urbanization, entrepreneurial activities, per capita renewable energy, financial innovation and environmental policy for selected regions in the referencing period 2000 - 2021. It was shown significant contribution of per capita green energy consumption, environmental policy and entrepreneurial activities toward environmental sustainability. Contrarily, income, financial inclusion and urbanization had been contributed to environmental damage (Udemba et al., 2024).

When considering the densely population regions with the emerging economies, it was argued an intensification of the ecological stress in both the short and long run. In the case of Somalia, and unlikely of other countries, it was not exhibited consistency with the Environmental Kuznets Curve hypothesis, implying the urgent need for targeted policy interventions (Abdi et al., 2025). In such a case the role of energy production and the specific socio-economic conditions can be considered. Indeed, by adopting renewable energy, integrating environmental education and implementing sustainable urban and economic strategies can distress ecological pressures and to simultaneously ensure long-term environmental sustainability. Such finding can also underscore those critical factors that policymakers among emerging economies should take into consideration, especially among those developing economies that are facing similar environmental challenges (Abdi et al., 2025).

This study provides a comparative case study on assessment of ecological footprint and biocapacity for Baltic States sharing the similar geographic and social-economic development conditions with the aim to reveal those distinct characteristics and to highlight the reasons of these observed differentiates.

Methodologies and Analytical Techniques

The theoretical production of linking ecological footprint and biocapacity towards sustainable development enabled the collection and presentation of the main methodologies and analytical techniques that have been employed. In this context these methodologies and techniques have been collected and presented in reverse chronological order, from the newest to the earliest, in the following Table 1.

Table 1. Methodologies and Analytical Tools. Source: Authors own study.

Reference	*Methodologies- Analytical tools*
Güler Et al., 2025	Remote sensing and GIS spatial analysis techniques were employed to investigate the impact of economic growth and foreign direct investment (FDI) on China's sustainable development goals (SDGs). Research focus on Zero Hunger (SDG 2), Life Below Water (SDG 14), and Life on Land (SDG 15). Ecological footprints and load capacity factors (LCFs) in cropland, fishing, forest, and grazing land were examined using Fourier bootstrap autoregressive distributed lag (ARDL) cointegration analysis and fully modified ordinary least squares (FMOLS) estimators.
Hong et al., 2024	Advanced econometric estimation methods have been employed.
lian, 2024	A robust panel estimation technique was employed, enabled authors to systematically explore the key-parameters of this study.
Mehmood, 2024	Annual data of 1990–2020 have been utilized to apply the cross-sectional autoregressive distributed lag approach and validates the Environmental Kuznets Curve in the G-11 eleven nations group.
Galli et al., 2023	Resource dependence and carbon emissions of the EU-27's food systems at the period 2004 - 2014 via an ecological footprint-extended multi-regional input–output approach The method counts for demand and supply (including trade), and consideried multiple externalities.
Kongbuamai et al., 2023	The Environmental Kuznets Curve framework was employed to explore the impacts of economic growth, energy consumption, information, and communication

	technology (ICT), and urbanization on the ecological footprint for the Next-11 (N-11) countries. The Driscoll––Kraay standard error and Feasible General Least Squares (FGLS) methods were applied to investigate the long-run relationship between the highlighted variables. In addition, the Dumitrescu and Hurlin panel causality test was employed for exploring the causality path of the variables under consideration.
Onifade, 2023	The Augmented Mean Group (AMG) estimator produced important information offering the additional advantage of exploring country-specific outcomes in the empirical analyses that were subsequently corroborated by the Dynamic Ordinary Least Square (DOLS) and Fully Modified Ordinary Least Square (FMOLS) approaches.
Sampene et al., 2023	The impact of economic growth, biocapacity, renewable energy use, natural resource rent, agricultural value-added, green finance and information and communication technology on the ecological footprint. The environmental Kuznets curve framework was employed with a dataset at the period 1990 - 2017. The cross-sectional-augmented autoregressive distributed lag (CS-ARDL) approach was applied to estimate the variable's short and long-term interaction.
Shen and Yue, 2023	The nonlinear impact of the ecological footprint on biocapacity from the perspective of the self-regulation capacity of the ecosystem provided a new perspective to value the sustainability satisfaction/experience of a country. Using panel data of the G20 countries, a panel smooth transition model with a continuous transition process was established. This model abandons the constraints of linear models and agrees with the gradual characteristics of ecosystem evolution.
Ahmed et al., 2022	Second generation econometric techniques were used of data analysis.
Boukhelkhal, 2022	The determinants of ecological footprint were identified as a proxy for environmental quality in Algeria in the period 1980 - 2017 using several economic indicators. The autoregressive distributed lags (ARDL) approach has been utilized in order to estimate the constructed environmental degradation models.
Qaiser Gillani et al., 2021	Fixed effects panel data estimations and the utility of the Hausman specification test have been counted for the fixed effects model as the suitable identification estimator.
Ullah et al., 2021	Panel time-series data in the period 1996 - 2018 has been focused on. Panel Smooth Transition Model has been utilized in order to explore the nonlinear relationship and transition between the low and the high regimes due to nonlinear behavior.
Majeed and Mazhar, 2020	Reinvestigation of the Environmental Kuznets Curve was materialized by exploiting the lager panel data set, covering a longer time horizon more than half century (1961-2018) and using ecological footprint as a comprehensive environmental indicator, while the employment of first-generation and second-generation panel time's series methods were undertaken.
Świąder et al., 2020	Considering annual data from 1990–2020 robust methodologies were employed to present the findings. The CS-ARDL method showed that jointly the renewable energy, ICT, and government stability played a pivotal role to moderate environmental pollution in G11 countries. Environmental Carrying Capacity (ECC) is a concept and a tool for the sustainable development of human settlements.In this study the utilization of the environmental indicators such as ecological footprint and biocapacity were employed for ECC quantification.
Udemba, 2020	Autoregressive Distributed Lag (ARDL) and Granger Causality (GC) methods.

Shujah-ur-Rahman et al., 2019	Having the research focus on the Central and Eastern European Countries (CEECs), in this study there is a cooperation among biocapacity and human capital in the growth–energy–environment nexus. Annual data of 16 CEE countries in perspective of the One Belt One Road (OBOR) initiative in the reference period of 1991–2014. This study has been focused on second-generation econometric approaches to check stationarity, cross-sectional dependency, and co-integration among the model parameters. The long-run estimations of the "Dynamic Seemingly Unrelated-co-integration Regression" (DSUR) disclosed an instability of economic growth on ecological footprint and validated the environmental quality through a N-shaped relationship for cubic functional form between per capita income and ecological footprint.
Olowu et al., 2018	Use of time series data on financial access (bank branches per 100,000 adults), financial depth (private credit by deposit money banks to GDP), financial efficiency (bank return on equity percentage, after tax), financial stability (bank Z-score), composite index for financial development, ecological footprint indicator and sustainable economic opportunity.
Niccolucci et.al., 2012	Footprint and biocapacity dynamics have been determined by many different factors, making each profile unique and complex to explain. Identification of four main dynamic typologies: parallel, scissor, wedge and descent. The evaluation criteria were that of population trends jointly with other indicators, including: environmental performance index, EPI, environmental sustainability index, ESI and human development index, HDI.
Yue et al., 2012	Remote sensing and GIS spatial analysis techniques.
Carlei et al., 2011	The Absolute Ecological Footprint instead the Pro-Capita was considered as a suitable proxy to effectively investigate socio-economic patterns of sustainable development. Setting out a methodology of non-linear analysis, based on Neural Networks Self Organizing Map in order to explore the relationship between different kinds of socio-economic patterns. Research focus on demonstrating the relevance of selected social-economic features as a complex factor for sustainable development.

Source: own

Concerns and considerations of linking ecological footprint and biocapacity towards sustainable development

Based on the theoretical background of the aforementioned published studies in linking ecological footprint and sustainable development, it can be inferred that the principles of sustainable development consist of economic, societal, and environmental considerations. All economic systems and social structures are more or less shaping social impacts on health, which are engaged with the broader environment and they are affecting the distribution of energy resources worldwide (Jie et al., 2023).

Among the socio-economic features of linking ecological footprint, economic growth and natural resources towards the accomplishment of sustainable development is the assessment of how education and life expectancy as social indicators can influence the environmental quality (Boukhelkhal, 2022). Considering the symbiosis of natural resources, population growth, and industrial development, contemporary studies are mainly concentrating on the impact of sustainable energy policy and socio-economic development on the ecological footprint, as in the case of China in the long-run period 1990-2019 (Jie et al., 2023). It was shown that the main contributors of natural net financial accounts, natural resources, and economic growth are all positively linked with the ecological footprint. In this context environmental sustainability is valued as a long-term result of socio-economic development (Jie et al., 2023). In approaching the determining factors of the theoretical coverage, a map of the CE-operational grid has been adopted and presented below, Figure 1.

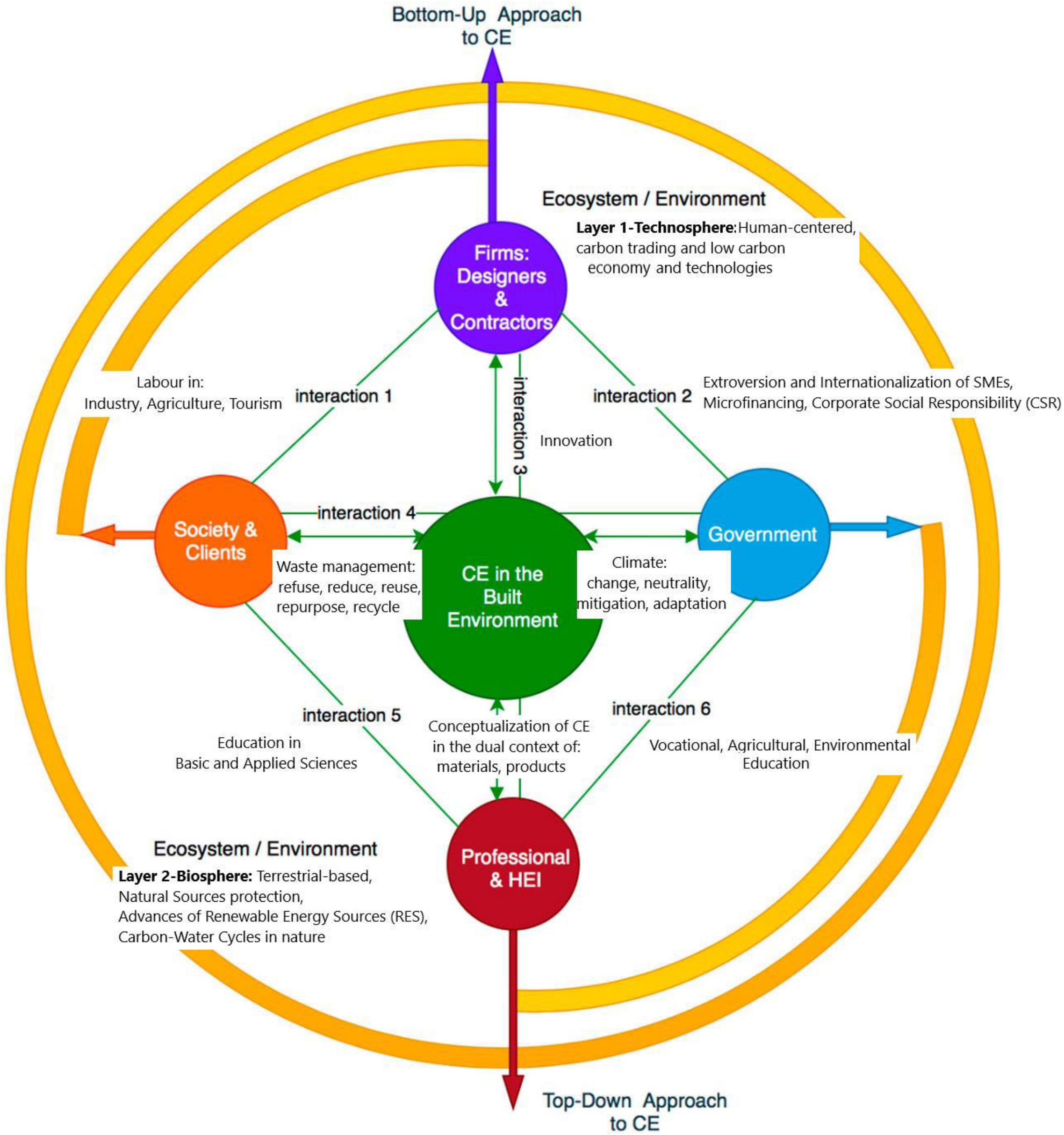

Figure 1. A map of the CE-operational grid. Source: Modified and enhanced from: Michael Atafo Adabre et al., (2024), Figure 2, p.4.

Based on the aforementioned CE-oriented map, it is noteworthy that there is currently nurtured a green energy supportive behavior that can make an additional step to investigate in a holistic approach the mediating effect on financial inclusion, environmental policy and entrepreneurship. However, such a mediating effect can only support environmental policy and entrepreneurship activities to reduce environmental pressure, whereas from the policy perspective, there is need of specified economies to allocate their financial resources to clean and green projects in order a credible and realistic level of sustainability to be developed (Udemba et al., 2024).

Some developing countries have shown poor health outcomes thus they are facing challenges to cope with sustainable economic development and governmental/national health expenditure based on ecological footprint consumption, in order more positive and prosperous outcomes for such goals to be attained (Qaiser Gillani et al., 2021). Therefore, public health expenditures and health outcomes among fast emerging economies should be identified in a long run period (Qaiser Gillani et al., 2021).

Regarding the biocapacity perspective it is critical to ensure that nations or countries can sustain its inhabitability and self-sufficiency in terms of natural resources, under the precondition that the total amount of biocapacity areas are equal to or higher than the ecological footprint. In the relevant literature an analytical study has been carried out to remedy the biocapacity deficit by utilizing this information for national data which can be optimized with heuristic optimization techniques (Pençe et al., 2024). Such a developed model can be used in other than environmental context, such as in the industrial sector or within the frame of national and governmental development policies to balance under control between ecological footprint and biocapacity (Pençe et al., 2024). Closing the theoretical background of this study it is noteworthy mentioning the following important aspects of it:

- Normally biocapacity decreases and ecological footprint increased whenever urbanization take place. Therefore, there is a causality between human capital, ecological footprint, urbanization and economic growth especially among emerging economies (Nathaniel, 2021). It is also noticeable a fundamental environmental challenge that especially developed and highly internationalized countries have to contend with, despite the fact they experience a high, or even tremendous, growth for decades (Nathaniel, 2021). Therefore, the critical point here is the identification and the functionality of influential tof biocapacity factors, like that of human capital and urbanization on the ecological footprint with advanced techniques that cope with core panel data issues having also the ability to derive country-specific results and to guide relevant policy recommendations and future research directions (Nathaniel, 2021).

- Among the far-reaching implications for ecosystems, economies, and societies worldwide is the challenge to confront climate change. In response to address this challenging issue the Human Capital (HUC) and the Economic Complexity (ECC) can be perceived as structural transformations toward more sophisticated and knowledge-based production, having also the pivotal ability in curtailing ecological degradation (Boukhelkhal, 2022; Hong et al., 2024). In this context, future research works can focus on deepening more systematic to intricate relationship between HUC, financial development, financial globalization, gross domestic product, ECC, and ecological footprints (Hong et al., 2024).

1. LITERATURE REVIEW

Research shows that economic growth can have varying effects on both Ecological Footprint (EF) and biocapacity across different countries. For example, while developing nations often experience a decline in biocapacity due to increasing ecological footprints, developed countries may enhance their biocapacity even in the presence of rising ecological footprints. This illustrates a complex relationship influenced by technological advancements and resource management practices The concepts of ecological footprint and biocapacity are critical for understanding sustainability and human impact on the environment. The ecological footprint measures the demand a population places on Earth's ecosystems in terms of the land and water required to produce the consumed resources and to assimilate the waste generated. In contrast, biocapacity refers to the capacity of an ecosystem to regenerate resources and provide services. The relationship between these two metrics defines ecological overshoot, which occurs when a population's ecological footprint exceeds its biocapacity, indicating unsustainable practices (AEFR (2012; Pençe et al., 2024).

The significance of ecological footprint analysis (EFA) lies in its ability to quantify environmental sustainability by assessing the pressure exerted on natural resources by human activities (Jiang and Li, 2010). For instance, Santoso et al. highlight how the ecological footprint can inform regional planning by identifying human activity-generated consumption patterns and contrasting them with available natural resources (Santoso et al., 2019). This method elucidates the balance—or imbalance—between ecological consumption and resource availability, offering strategic insights for sustainable development efforts (Mishra et al., 2025).

The ecological footprint serves as a tangible metric to quantify the environmental impact associated with human consumption patterns, while biocapacity defines the ecosystem's ability to regenerate resources and assimilate wastes. This relationship is pivotal in recognizing ecological overshoot, where human demands exceed what the planet can sustainably provide. Therefore, the Sustainable development can be assessed with two overarching indicators. The first indicator is the United Nations' Human Development Index (HDI), which measures how well a country's residents live by tracking the country's achievements in longevity, access to education, and income. An HDI higher than 0.7 is "high human development". The second indicator is the ecological footprint, which measures whether humanity lives within the means of nature. An ecological footprint of less than 1.5 global hectares per person makes the resource to be consumed at a slower rate than that of replenishing it. Actually, it should be significantly less than 1.5 gha/person if we want to maintain biodiversity and leave space for wild species (AEFR, 2012). However, given growing populations and recognizing wild species' needs for biocapacity, the average ecological footprint per person worldwide needs to fall significantly below this threshold. he Ecological Footprint can be measured in either global hectares per person or in "Number of Earths", which represents how many Earths would be required to support humanity of everyone had that ecological footprint (Rao, 2024).

The intricate interplay between ecological footprint and biocapacity underscores critical implications for policymaking. Effective environmental policies must be grounded in the evaluation and management of both metrics to prioritize sustainable resource practices. For instance, the establishment of carbon pricing mechanisms has demonstrably contributed to reducing footprints while promoting sustainable economic growth (Skare et al., 2024). Furthermore, regional planning that emphasizes biocapacity optimization can guide land-use decisions to ensure that communities operate within their ecological limits (Guo et al., 2017).

Technological innovations play a crucial role in managing ecological footprint and enhancing biocapacity. Advances in precision agriculture, renewable energy, and waste management significantly contribute to mitigating resource consumption. The integration of ICT facilitates efficient monitoring of resource use and promotes environmentally friendly practices across sectors. The role of e-commerce suggests that digital platforms can enhance the sustainability of business operations and contribute positively to achieving the SDGs (Kongbuamai et al., 2023).

Despite the promise that ecological footprint and biocapacity measurements hold for informing sustainability, challenges persist. The primary limitations lie in data accuracy, especially in regions with incomplete statistics and environmental assessments. Differences in local ecosystem productivity complicate the efficacy of generalized assessments, particularly when applied across diverse geographical contexts (Carlei et al., 2011). Furthermore, the emergence of environmental carrying capacity assessment presents an evolving framework necessitating interdisciplinary approaches that consider social, economic, and ecological systems (Yue et al., 2012). The development of region-specific models offers the potential for tailored solutions addressing unique environmental challenges, such as those found in industrial growth regions and urban centers (Jie et al., 2023; Udemba et al., 2024)

As the need for sustainable practices becomes increasingly urgent, it is important to develop comparative case studies on ecological footprint and biocapacity assessments to emphasize the potential for integration of otherwise diversified policies in order to harmonize the principles of sustainability across diverse sectors (Onifade, 2023).

The ecological footprint and biocapacity metrics provide essential frameworks for evaluating sustainability. Understanding their interdependencies is critical for formulating policies that aim to balance human development and environmental conservation. Future research should focus on refining measurement techniques and improving the integration of these metrics into policy frameworks to support sustainable practices globally.

2. METHODS AND DATA

2.1 Ecological Footprint and Biocapacity

The ecological footprint is quantified as the amount of biologically productive land and water area required to support a population's consumption and waste generation (Venetoulis & Talberth, 2007). This measure has evolved to encompass various consumption categories, including food, energy, and goods. The methodology for calculating ecological footprints can be broadly categorized into top-down approaches, relying on national or regional statistics, and bottom-up assessments, which involve individual-level data collection (Jiang and Li, 2010). Recent research efforts have illustrated the use of diverse methodologies, including input-output analysis and life cycle assessment (LCA), which allow for a more comprehensive understanding of ecological impacts (Santoso et al., 2019).

Biocapacity refers to the capacity of ecosystems to regenerate resources and provides a measure of the ecological services they can sustainably yield. Recent studies have utilized sophisticated theoretical models to evaluate environmental carrying capacity, addressing deficits and surpluses in resource availability in specific regions (Li et al., 2019). Emerging methodologies increasingly incorporate data-driven approaches that combine geographical and ecological factors for more precise assessments of biocapacity (Lin et al., 2023). The integration of emergy analysis, as demonstrated by Jung et al., enhances insights into vulnerabilities that could impede sustainable development and offers a novel perspective on measuring carrying capacity (Jung et al., 2018).

The relationship between ecological footprint and biocapacity is fundamental to understanding sustainability. When a community's ecological footprint exceeds its biocapacity, it enters a state of ecological overshoot, which can have damaging long-term consequences for the environment. Research indicates a global trend of increased ecological overshoot over recent decades, highlighting the urgent need for sustainable practices (Fanning et al., 2022). In specific case studies, such as those investigating industrial centers in the Yangtze River Economic Belt, correlations between resource utilization and environmental stress are observed, emphasizing the importance of effective governance in addressing these challenges (Bao et al., 2020; Wang et al., 2019).

Globally, variations in ecological footprints and biocapacity reflect disparate levels of consumption, technological advancement, and resource management practices. Countries like China present a stark example of these dynamics; as the economy has rapidly expanded, ecological footprints in urban areas have frequently surpassed local biocapacity, resulting in severe environmental degradation (Boukhelkhal, 2022; Hong et al., 2024). Studies cite the importance of regional assessments, such as those conducted in Xinbei District, Changzhou, which provide localized data on carrying capacity and illuminate the distinct pressures faced by urbanizing areas Li et al., 2019). In contrast, less developed regions may face a declining biocapacity due to insufficient infrastructure for resource conservation (AEFR, 2012).

The methodology of Ecological Footprint and Biocapacity is a quantitative approach used to assess the sustainability of human activities by comparing the demand placed on nature with the Earth's capacity to regenerate resources and absorb waste. The Ecological Footprint measures the biologically productive land and water area required to produce the resources a population consumes and to absorb the associated waste, particularly carbon emissions. This includes areas needed for food production (cropland and grazing land), fishing, forest products, built-up infrastructure, and carbon sequestration (AEFR, 2012). In contrast, Biocapacity represents the Earth's biological ability to provide renewable resources and absorb wastes, considering the productivity of different land types. Biocapacity is the capacity of ecosystems to regenerate what people demand from those surfaces (e.g., produce food, absorb CO_2). It is measured in the same units (gha), biocapacity depends on: Land area available, Yield factors (productivity of a region compared to global average). Equivalence factors (convert land types to a common unit, i.e., gha). Both metrics are measured in a common unit called global hectares (gha), which standardizes the productivity of various ecosystems. The Earth assessment involves comparing the global or national Ecological Footprint with the corresponding Biocapacity. If a population's Footprint exceeds its Biocapacity, it results in an ecological deficit, indicating that it is depleting natural capital or depending on imports or global commons (like the atmosphere). If the Footprint is lower than the biocapacity, there is an ecological reserve

(Pençe et al., 2024). An ecological deficit occurs when the Ecological Footprint of a population exceeds the biocapacity of the area available to that population. A national ecological deficit means that the country is net-importing biocapacity through trade, liquidating national ecological assets or emitting more carbon dioxide waste into the atmosphere than its own ecosystems absorb. In contrast, an ecological reserve exists when the biocapacity of a region exceeds its population's ecological footprint (Pençe et al., 2024).

3. CASE STUDY

The data for Baltic States on biocapacity and carbon footprint was derived from Global Footprint Network (2021; 2025)

In Figure 2 the development of biocapacity per capita in Baltic States during 1992-2022 year period provided.

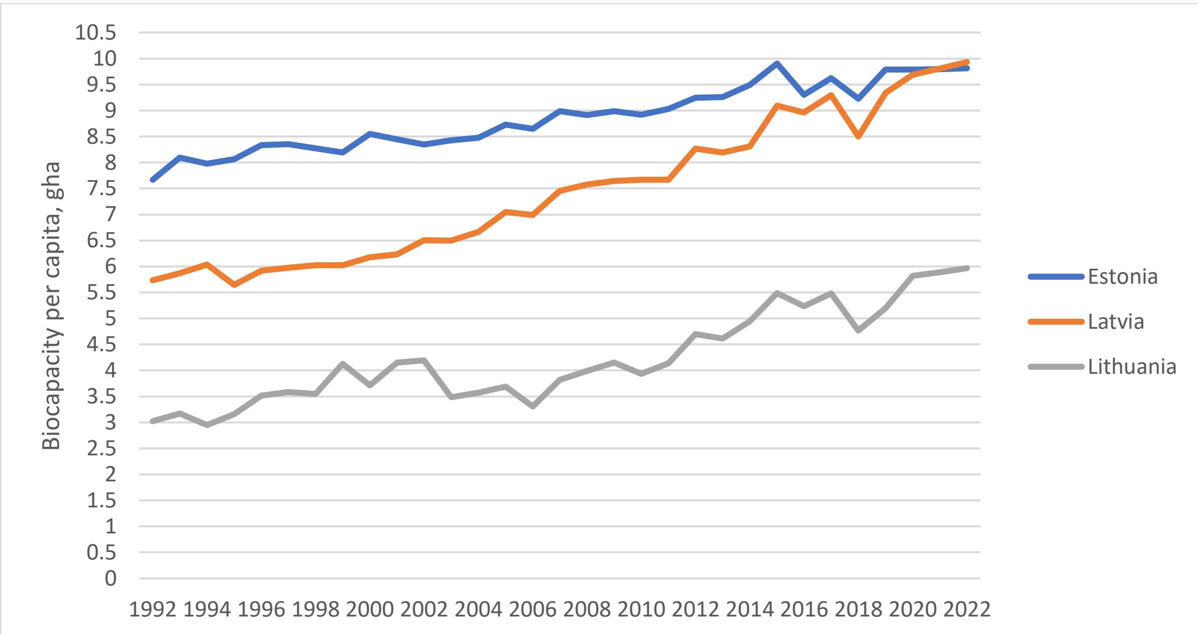

Figure 2. Development of biocapacity per capita in Baltic States

Figure 2 shows that vver the 30-year period, Estonia consistently was showing the highest biocapacity per capita among the Baltic States. This is likely due to its relatively low population density and large forested areas, which contribute positively to biocapacity. Latvia also maintains moderate biocapacity levels, while Lithuania exhibits the lowest biocapacity per capita. This gap may stem from differences in land use intensity, natural resource endowment, or environmental management practices. Trends over time show a gradual decline in biocapacity across all three countries, reflecting increasing pressure on land resources, land degradation, or urban expansion. The decline is most pronounced in Lithuania, indicating that it may be more vulnerable to ecological stress or less effective in conserving its natural resource base.

In Figure 3 the development of ecological footprint per capita in Baltic States during 1992-2020 period is provided.

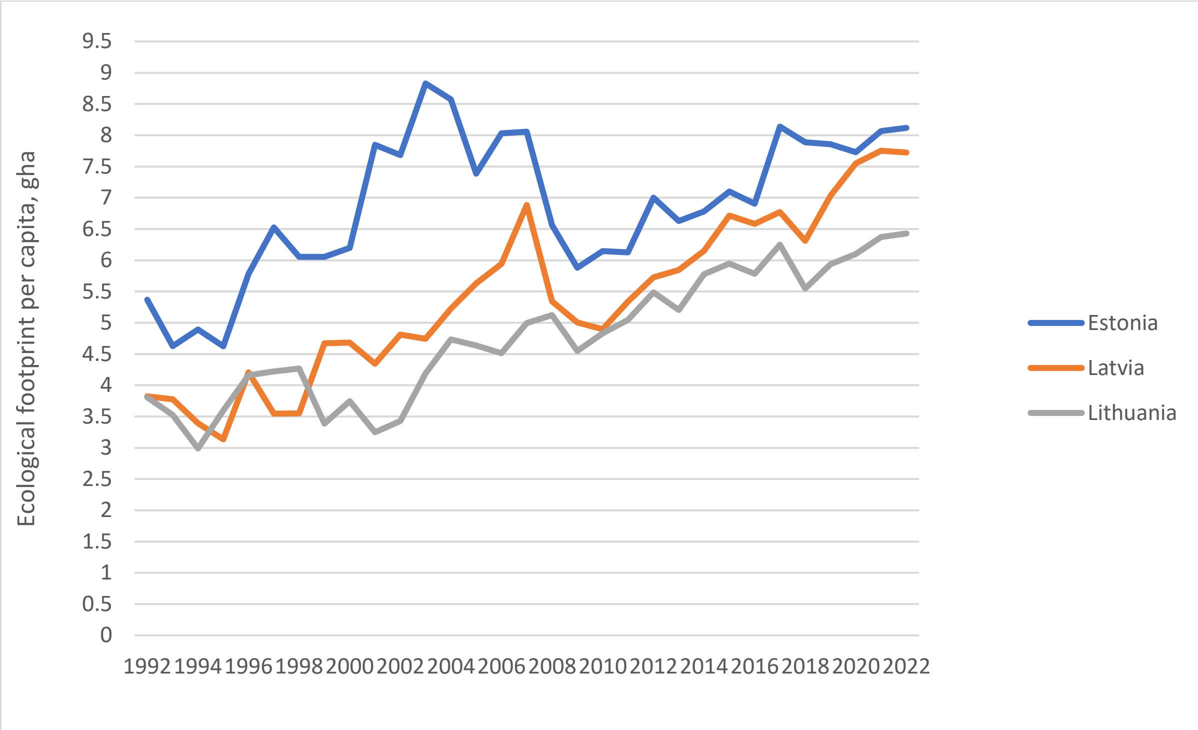

Figure 3. Development of ecological footprint per capita in Baltic States, gha

As one can notice from Figure 3 in contrast to biocapacity, the ecological footprint per capita has varied more dynamically over time, particularly reflecting economic changes in Baltic States. Estonia shows the highest and most volatile footprint, particularly in periods of rapid economic growth or high energy consumption. Its heavy reliance on oil shale energy could explain higher carbon emissions contributing to the footprint. Lithuania and Latvia have lower footprints, but Lithuania's footprint has shown a steady increase, particularly after the early 2000s, reflecting rising consumption and economic development. Latvia has the lowest footprint among the three, suggesting either lower per capita consumption or more energy-efficient practices. While, Estonia benefits from high biocapacity, it also exerts the greatest environmental pressure, potentially placing it at risk of overshooting its resources unless policy interventions are strengthened.

In Figure 4 the dynamics of biocapacity reserve or deficit of Baltic States during 1992-2023 period is provided.

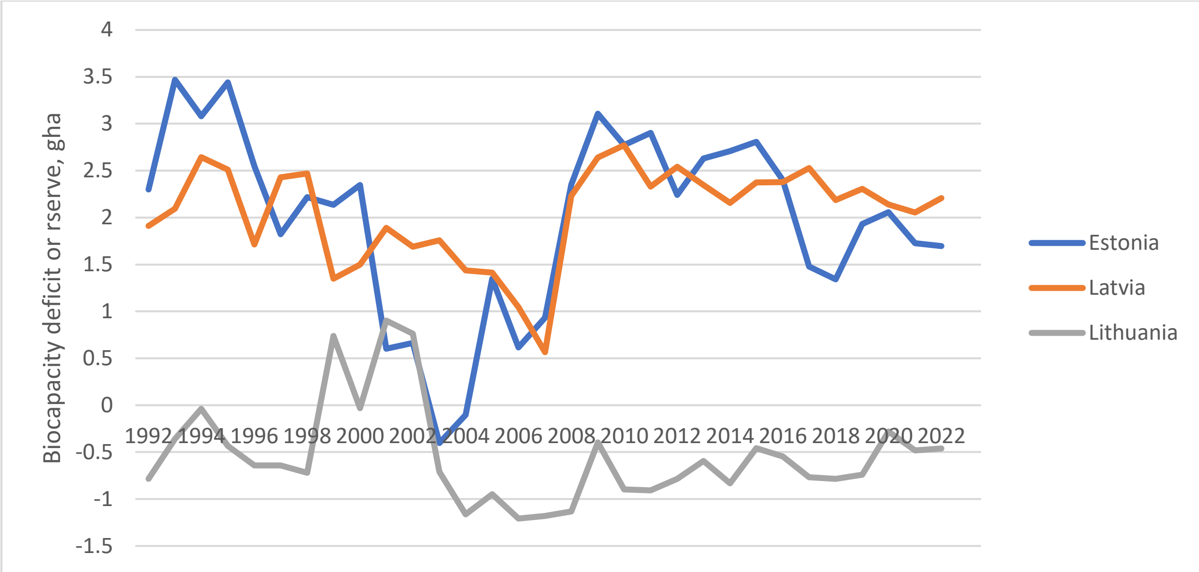

Figure 4. Development of biocapacity reserve of deficit in Baltic States

As one can notice from Figure 4, Estonia appears to fluctuate between ecological reserve and deficit, depending on how much its ecological footprint exceeds or remains within its biocapacity. Despite its high biocapacity, its high footprint brings it close to or into deficit in many years. Latvia tends to maintain a more stable ecological reserve, suggesting a better alignment between consumption and resource availability. This may reflect a more balanced development path or stronger environmental policies. Lithuania, on the other hand, consistently experiences an ecological deficit, as its growing footprint surpasses its comparatively low biocapacity. This highlights the greatest sustainability challenge among the three and indicates the need for stronger measures to curb resource use and improve ecosystem productivity.
In Figure 5 the dynamics of ecologocal footprint converted to Earths during 1992-2022 is provided for Baltic States.

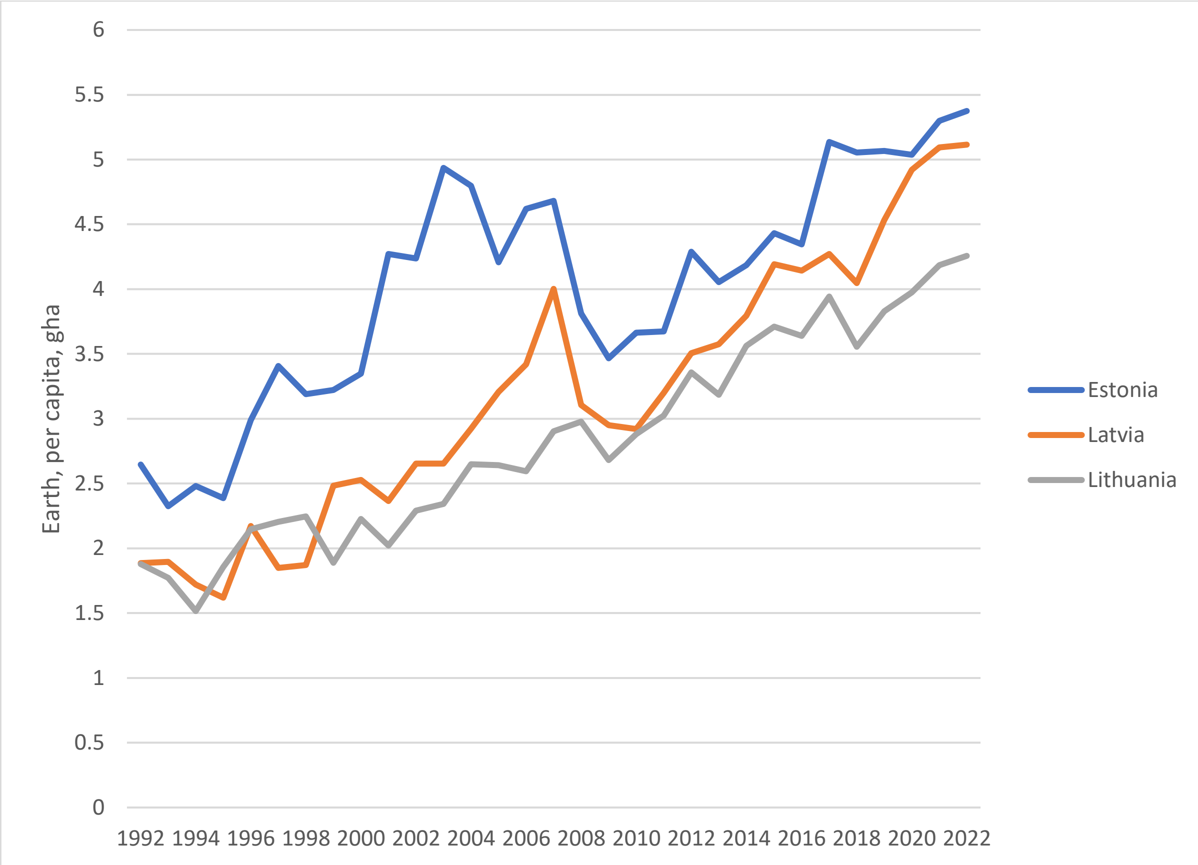

Figure 5. Development of earth in Baltic States

Figure 4 translates ecological footprint into a more relatable metric: how many Earths would be required if the global population consumed resources at the same rate. Estonia reaches values above 1 Earth, signaling unsustainable consumption levels, especially during periods of high economic activity. Lithuania also trends toward 1 or slightly above, consistent with its ecological deficit, while Latvia remains closer to 1 Earth or slightly below, indicating relatively more sustainable living standards. This metric underscores that none of the Baltic States consistently operate within globally sustainable limits, though Latvia comes closest, while Estonia and Lithuania exceed the Earth's regenerative capacity in many years.

The comparative analysis of ecological footprint and biocapacity across the Baltic States—Estonia, Latvia, and Lithuania—reveals distinct sustainability trajectories despite shared geographical and socio-economic conditions. Estonia stands out for its high biocapacity per capita, largely attributable to its vast forest resources and low population density. However, its advantage is offset by a consistently high ecological footprint, primarily driven by energy-intensive sectors such as oil shale-based electricity production. This duality places Estonia in a precarious position where it oscillates between ecological reserve and deficit.

Latvia, by contrast, presents a relatively balanced profile. It has moderate biocapacity levels and the lowest ecological footprint among the three countries. This equilibrium allows Latvia to maintain a stable ecological reserve over time, reflecting more sustainable consumption patterns, possibly aided by energy efficiency policies, moderate industrialization, and strong environmental governance. The trend suggests that Latvia may serve as a model of sustainable development for the region.

Lithuania, however, faces the most persistent ecological challenges. It has the lowest biocapacity per capita, likely due to higher population density and limited forest coverage. At the same time, its ecological footprint has increased steadily over the decades, reflecting economic growth accompanied by rising energy and material consumption. Consequently, Lithuania exhibits a long-term ecological deficit, which signals the urgency for comprehensive environmental reforms, especially in the energy, transportation, and land-use sectors.

The use of the “number of Earths” metric (Figure 5) illustrates the global implications of national consumption patterns. Estonia and Lithuania frequently exceed the one Earth threshold, indicating that their lifestyles, if adopted globally, would require more than one planet to sustain. Latvia, while closer to the sustainability line, still occasionally breaches the limit, underscoring that even the best-performing Baltic State has room for improvement.

The differences in ecological footprint and biocapacity among the Baltic States—Estonia, Latvia, and Lithuania—can be attributed to a combination of natural resource endowments, energy structures, demographic characteristics, economic development patterns, and policy priorities. Although these countries share similar historical, geographical, and socio-economic backgrounds, several key factors explain their divergent sustainability profiles.

One of the most significant drivers of difference lies in biocapacity, which is largely influenced by the availability and productivity of biologically active land. Estonia has the highest biocapacity per capita due to its large forest cover and low population density. This extensive ecological resource base contributes significantly to its overall regenerative capacity. In contrast, Lithuania has the lowest biocapacity per capita, primarily due to more intensive land use, higher population density, and a smaller proportion of forested and undeveloped land. Latvia falls between the two, with a more balanced distribution of land resources and moderate population pressure, resulting in stable biocapacity levels over time.

In addition, energy consumption structure plays a crucial role in determining ecological footprint, especially the carbon footprint, which forms a major component. Estonia's high ecological footprint is largely driven by its continued reliance on oil shale, one of the most carbon-intensive energy sources. Despite its small size, this fossil fuel use significantly inflates Estonia’s footprint per capita, especially during periods of economic growth. On the other hand, Latvia and Lithuania have more diversified and less carbon-intensive energy systems, with greater shares of hydropower (Latvia), biomass, and imported electricity. Latvia, in particular, has benefited from an energy mix that includes a relatively high proportion of renewable energy, helping it maintain a lower footprint.

The structure of the economy and patterns of consumption also impact ecological footprint. Estonia has a higher per capita income than the other two countries and a more industrialized economy, which correlates with greater consumption of energy and goods. This leads to a larger ecological footprint, despite high biocapacity. It can be stated that Lithuania’s economy has grown rapidly, especially after EU accession, leading to increased material and energy consumption. This economic expansion, while beneficial in terms of income and development, has outpaced gains in ecological efficiency, resulting in a rising ecological deficit.

Latvia, meanwhile, has had slower and more measured economic growth, which has likely helped it to stay within or near its biocapacity limits. Additionally, its relatively conservative consumption patterns and lower energy intensity have contributed to its better sustainability performance.

These findings underscore the critical importance of tailoring sustainability policies to national contexts. Estonia’s energy system requires urgent decarbonization, Lithuania must prioritize land and resource conservation, while Latvia should aim to preserve and refine its relatively favorable position. Cross-country collaboration in knowledge sharing and environmental policy harmonization could further strengthen the region’s overall sustainability.

CONCLUSION

The concepts of ecological footprint and biocapacity provide essential frameworks for evaluating environmental sustainability and guiding human development. Understanding their interdependencies is critical for formulating policies that seek to balance economic growth with environmental protection. As global environmental pressures continue to escalate, the integration of technological innovation, sound resource management, and equitable socio-economic practices will prove indispensable in achieving sustainable development goals.

This study highlights the value of ecological footprint and biocapacity metrics as essential tools for assessing and guiding sustainable development. By examining the Baltic States over a 30-year period, the paper demonstrates significant variations in environmental performance, despite similarities in regional characteristics.

Latvia emerges as the most balanced in terms of sustainability, maintaining a relatively low ecological footprint and a stable biocapacity, which allows it to remain within the Earth's ecological limits more consistently. Estonia, while rich in ecological assets, risks undermining its environmental advantages due to high carbon emissions and consumption levels. Lithuania, on the other hand, faces the greatest environmental pressure, with persistent ecological deficits driven by low biocapacity and growing demand.

The trends call for differentiated policy responses. Estonia should focus on energy diversification and carbon intensity reduction, Lithuania must enhance biocapacity through land and ecosystem restoration, and Latvia should reinforce its current path with continuous innovation in sustainable development practices.

The ecological footprint framework offers a valuable lens for policymakers to understand and address ecological limits. Its integration into national sustainability strategies can guide the Baltic States toward a future that aligns economic progress with environmental stewardship.

REFERENCES

Abdi, A.H., Mohamed, A.A., Mohamed, M.A. (2025), "Education for sustainable development in Somalia: do economic growth, energy consumption, and population density affect ecological footprints?", Discover Sustainability, Vol. 6, No. 1, pp. 292. DOI: 10.1007/s43621-025-01019-w

Adabre, M. A., Chan, A. P. C., Darko, A., Edwards, D. J., Yang, Y., Issahaque, S. (2024), "No Stakeholder Is an Island in the Drive to This Transition: Circular Economy in the Built Environment", Sustainability, Vol. 16, No. 15, pp. 6422. https://doi.org/10.3390/su16156422.

Adabre, M.A., Chan, A.P.C., Darko, A., Edwards, D.J., Yang, Y., Issahaque, S. (2024), "No Stakeholder Is an Island in the Drive to This Transition: Circular Economy in the Built Environment", Sustainability, Vol. 16, No. 15, pp. 6422. https://doi.org/10.3390/su16156422.

AEFR (2012), "Africa Ecological Footprint Report: Green Infrastructure for Africa's Ecological Security", pp. 72. ISBN 978-2-940443-39-0. Available at https://www.afdb.org/sites/default/files/documents/projects-and-operations/africa_ecological_footprint_report_-_green_infrastructure_for_africas_ecological_security.pdf (Accessed on 10 May 2025).

Ahmed, Z., Ahmad, M., Rjoub, H., Kalugina, O.A., Hussain, N. (2022), "Economic growth, renewable energy consumption, and ecological footprint: Exploring the role of environmental regulations and democracy in sustainable development", Sustainable Development, Vol. 30, No. 4, pp. 595-605. DOI: 10.1002/sd.2251.

Bao, H., Wang, C., Han, L., Wu, S., Lou, L., Xu, B., Liu, Y. (2020), "Resources and Environmental Pressure, Carrying Capacity, And Governance: A Case Study of Yangtze River Economic Belt", Sustainability, Vol. 12, No. 4, pp. 1576. https://doi.org/10.3390/su12041576.

Boukhelkhal, A. (2022), “Impact of economic growth, natural resources and trade on ecological footprint: do education and longevity promote sustainable development in Algeria?”, International Journal of Sustainable Development and World Ecology, Vol. 29, No. 8, pp. 875-887. DOI: 10.1080/13504509.2022.2112784.

Carlei, V., Colantonio, E., Furia, D., Mattoscio, N. (2011), “Economic patterns of sustainable development: An analysis of absolute ecological footprint through self-organizing map”, Quality and Quantity, Vol. 45, No. 1, pp. 157-171. DOI: 10.1007/s11135-010-9362-4.

Fanning, A.L., O’Neill, D.W., Hickel, J., Roux, N. (2022), „The social shortfall and ecological overshoot of nations“, Nature Sustainability, Vol. 5, pp. 26–36. https://doi.org/10.1038/s41893-021-00799-z.

Galli A., Antonelli M., Wambersie L., Bach-Faig A., Bartolini F., Caro D., Iha K., Lin D., Mancini M.S., Sonnino R., Vanham D., Wackernagel M. (2023), “EU-27 ecological footprint was primarily driven by food consumption and exceeded regional biocapacity from 2004 to 2014”, Nature Food, Vol. 4, No. 9, pp. 810-822. DOI: 10.1038/s43016-023-00843-5.

Global Footprint Network (2025), Available at https://data.footprintnetwork.org/?_ga=2.194075626.657601560.1747566889-1053040308.1747566056#/ (Accessed on 10 May 2025).

Global Footprint Network. (2021), “What is the Ecological Footprint?” Available at: https://www.footprintnetwork.org (Accessed on 10 May 2025).

Güler, İ., Naimoğlu, M., Şimşek, O., Adalı, Z., Özbek, S. (2025), “Analyzing the impact of economic growth and FDI on sustainable development goals in China: insights from ecological footprints and load capacity factors”, Frontiers in Environmental Science, Vol. 13, pp. 1513158. DOI: 10.3389/fenvs.2025.1513158. (Accessed on 10 May 2025).

Guo, J., Yue, D., Li, K., Hui, C. (2017), “Biocapacity optimization in regional planning”, Scientific Reports, Vol. 7, No. 41150. DOI: 10.1038/srep41150.

Hong, T., Yin, J., Latif, M.N., Ahmad, M. (2024), “Human capital, economic complexity, and ecological footprints: Crafting a sustainable development policy framework for E7 nations”, Natural Resources Forum, Vol. 48, No. 4, pp. 1494-1511. DOI: 10.1111/1477-8947.12520.

Jiang, S., Li, X. (2010),“Study on Harmonizing Land-use and Ecological Environment Based on Ecological Footprint: A Case Study of Gu'an County, Hebei in China”, The 2010 International Conference on Environment and BioScience (ICEBS 2010), pp. 203-207.

Jie, H., Khan, I., Alharthi, M., Zafar, M.W., Saeed, A. (2023), “Sustainable energy policy, socio-economic development, and ecological footprint: The economic significance of natural resources, population growth, and industrial development”, Utilities Policy, Vol. 81, No. 101490. DOI: 10.1016/j.jup.2023.101490.

Jung, C., Kim, C., Kim, S., Suh, K. (2018), “Analysis of Environmental Carrying Capacity with Emergy Perspective of Jeju Island” Sustainability, Vol. 10, No. 5, pp. 1681. https://doi.org/10.3390/su10051681.

Kongbuamai, N., Bui, Q., Adedoyin, F.F., Bekun, F.V. (2023), “Developing environmental policy framework for sustainable development in Next-11 countries: the impacts of information and communication technology and urbanization on the ecological footprint”, Environment, Development and Sustainability, Vol. 25, No. 10, pp. 11307-11335. DOI: 10.1007/s10668-022-02528-8.

Li, K., Jin, X., Ma, D., Jiang, P. (2019), “Evaluation of Resource and Environmental Carrying Capacity of China’s Rapid-Urbanization Areas—A Case Study of Xinbei District, Changzhou”, Land, Vol. 8, No. 4, pp. 69. https://doi.org/10.3390/land8040069.

Lian, M. (2024), “The impact of cleaner energy sources, advanced technology firms, and economic expansion on ecological footprints is critical in sustainable development”, Heliyon, Vol. 10, No. 11, pp. 31100. DOI: 10.1016/j.heliyon.2024.e31100.

Lin, A., Liu, Y., Zhou, S., Zhang, Y., Wang, C., Ding, H. (2023), “Data-Driven Analysis and Evaluation of Regional Resources and the Environmental Carrying Capacity”, Sustainability, Vol. 15, No. 10, pp. 8372. https://doi.org/10.3390/su15108372.

Majeed, M.T., Mazhar, M. (2020), “Reexamination of environmental Kuznets curve for ecological footprint: The role of biocapacity, human capital, and trade”, Pakistan Journal of Commerce and Social Sciences, Vol. 14, No. 1, pp. 202-254.

Mehmood, U. (2024), “Assessing the Impacts of Eco-innovations, Economic Growth, Urbanization on Ecological Footprints in G-11: Exploring the Sustainable Development Policy Options”, Journal of the Knowledge Economy. DOI: 10.1007/s13132-024-01759-6.

Mehmood, U., Agyekum, E.B., Kotb, H., Milyani, A.H., Azhari, A.A., Tariq, S., Haq, Z.U., Ullah, A., Raza, K., Velkin, V.I. (2022), “Exploring the Role of Communication Technologies, Governance, and Renewable Energy for Ecological Footprints in G11 Countries: Implications for Sustainable Development”, Sustainability, Vol. 14, No. 19, pp. 12555. DOI: 10.3390/su141912555.

Mishra, R.-K., Mishra, D., Agarwal, R. (2025), “Environmental sustainability and ecological balance”, In book: Implementation of Innovative Strategies in Integral Plant Protection,

Publisher: Bhumi Publishing, India, pp.81-103.

Nathaniel, S.P. (2021), “Biocapacity, human capital, and ecological footprint in G7 countries: the moderating role of urbanization and necessary lessons for emerging economies”, Energy, Ecology and Environment, Vol. 6, No. 5, pp. 435-450. DOI: 10.1007/s40974-020-00197-9.

Niccolucci, V., Tiezzi, E., Pulselli, F.M., Capineri, C. (2012), “Biocapacity vs Ecological Footprint of world regions: A geopolitical interpretation”, Ecological Indicators, Vol. 16, pp. 23-30. DOI: 10.1016/j.ecolind.2011.09.002.

Olowu G., Bein M., Olasehinde-Williams G. (2018), „Examining the relationship between financial development, sustainable economic opportunity and ecological footprint in SADC countries“, Applied Ecology and Environmental Research, Vol. 16, No.5, pp. 7171-7190. DOI: 10.15666/aeer/1605_71717190

Onifade, S.T. (2023), “Environmental impacts of energy indicators on ecological footprints of oil-exporting African countries: Perspectives on fossil resources abundance amidst sustainable development quests”, Resources Policy, Vol. 82, No. 103481. DOI: 10.1016/j.resourpol.2023.103481.

Pençe, İ., Çeşmeli, M.Ş., Kumaş, K., Akyüz, A., Tuncer, A.D., Güngör, A. (2024), “Study of biocapacity areas to reduce ecological footprint deficits: A case study of Turkey”, Science of the Total Environment, Vol. 932, No. 173018. DOI: 10.1016/j.scitotenv.2024.173018.

Qaiser Gillani, D., Gillani, S.A.S., Naeem, M.Z., Spulbar, C., Coker-farrell, E., Ejaz, A., Birau, R. (2021), “The nexus between sustainable economic development and government health expenditure in Asian countries based on ecological footprint consumption”, Sustainability, Vol. 13, No. 12, pp. 6824. DOI: 10.3390/su13126824.

Rao, P. (2024), “GreenThe Number of Earths Needed for Different Countries’ Lifestyles”, Availability at https://www.visualcapitalist.com/the-number-of-earths-needed-for-different-countries-lifestyles/ . (Accessed on 10 May 2025).

Sampene, A.K., Li, C., Khan, A., Agyeman, F.O., Brenya, R., Wiredu, J. (2023), “The dynamic nexus between biocapacity, renewable energy, green finance, and ecological footprint: evidence from South Asian economies”, International Journal of Environmental Science and Technology, Vol. 20, No. 8, pp. 8941-8962. DOI: 10.1007/s13762-022-04471-7.

Santoso, E.B., Aulia, B.U., Aninditya, D.N. (2019), “Estimation of Ecological Footprint for Sidoarjo Regency and its Implication towards Spatial Development”, IOP Conference Series Earth and Environmental Science, Vol. 313, No. 1, pp. 012047.

Shen, Y., Yue, S. (2023), “Does ecological footprint affect biocapacity? Evidence from the experiences of G20 countries”, Natural Resource Modeling, Vol. 36, No. 3, pp. 12369. DOI: 10.1111/nrm.12369.

Shujah-ur-Rahman, Chen S., Saud S., Saleem N., Bari M.W. (2019), “Nexus between financial development, energy consumption, income level, and ecological footprint in CEE countries: do human capital and biocapacity matter?”, Environmental Science and Pollution Research, Vol. 26, No. 31, pp. 31856-31872. DOI: 10.1007/s11356-019-06343-z.

Skare, M., Gavurova, B., Porada-Rochon, M. (2024), “Digitalization and carbon footprint: Building a path to a sustainable economic growth”, Technological Forecasting and Social Change, Vol. 199, pp. 123045. https://doi.org/10.1016/j.techfore.2023.123045.

Świąder M., Lin D., Szewrański S., Kazak J.K., Iha K., van Hoof J., Belčáková I., Altiok S. (2020), „The application of ecological footprint and biocapacity for environmental carrying capacity assessment: A new approach for European cities“, Environmental Science and Policy, Vol. 105, pp. 56-74. DOI: 10.1016/j.envsci.2019.12.010.

Udemba, E.N. (2020), A sustainable study of economic growth and development amidst ecological footprint: New insight from Nigerian Perspective. Science of the Total Environment, Vol. 732, No. 139270. DOI: 10.1016/j.scitotenv.2020.139270.

Udemba, E.N., Shah, S.A.R., Philip, L.D., Zhao G. (2024), „The mediating role of green energy and environmental policies in sustainable development for BRICS economies: A tripartite impact of entrepreneurial activities, urban development and economic growth on ecological footprint“, Sustainable Development, Vol. 32, No 5, pp. 4649-4670. DOI: 10.1002/sd.2916.

Ullah, A., Ahmed, M., Raz,a S.A., Ali, S. (2021), „A threshold approach to sustainable development: Nonlinear relationship between renewable energy consumption, natural resource rent, and ecological footprint“, Journal of Environmental Management, Vol. 295, No. 113073. DOI: 10.1016/j.jenvman.2021.113073.

Wang, Y., Peng, B., Wei, G., Elahi, E. (2019), "Comprehensive Evaluation and Spatial Difference Analysis of Regional Ecological Carrying Capacity: A Case Study of the Yangtze River Urban Agglomeration", International Journal of Environmental Research and Public Health, Vol. 16, No. 18, pp. 3499. https://doi.org/10.3390/ijerph16183499 .

Yue, D., Zhang, J., Guo, J., Du, J., Ma, J., Meng, X. (2012), „An analysis of sustainable development based on a comparison of the pre- and post- disaster biocapacity and ecological footprint in Zhouqu County, China“, Advanced Materials Research, 361-363, pp. 663-670. DOI: 10.4028/www.scientific.net/AMR.361-363.663.