VOL. 13 NO. 6,
AUGUST, 2026
E-ISSN 3027-1401
P-ISSN 3026-9148

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Arts and Sociological Research (JASR)

An Assessment of Socio-Economic Determinants of Bio-Economy in the EU Member States: An Ecological Footprint and Bio-Capacity Perspective

***Hammayo Abubakar Hammayo; **Muhammad Salim Hamisu; & *Sulaiman Tolba Magaji**

*Department of Economics & Development Studies, Federal University of Kashere (FUK), P.M.B 0182, Gombe State, Nigeria. **Department of Economics, Umaru Musa Yar' Adua University Katsina (UMYUK), P.M.B 2218, Katsina State, Nigeria
Corresponding Author: hammayo86@fukashere.edu.ng
DOI: https://doi.org/10.70382/ajasr.v13i6.0145

Abstract

The study critically assessed the bio-economic dependence of EU member nations on natural indicators such as ecological footprints, bio-capacity, ecological reserve and carbon footprints by employing a panel ARDL estimation technique over a given period of (2019-2023). The study further employed the marginal effect technique to investigate the rate of changes in bio-economy in the EU member nations given periodic ecological footprints and certain levels of carbon footprints. The study sourced data from the Global Footprint Network (GFN), EU National Footprint Accounts (NFA) and EU commission monitoring Agro-food trade development for a given range of (2019-2023) for the selected variables of interest. Based on empirical evidence, findings from this study suggest a long run relationship (cointegration) among the estimated variables. The long-run estimates suggests that the interaction of ecological and carbon footprints has a reducing effect on bio-economy while bio-capacity improves it for the EU member nations. Also, the values obtained from the NFA shows an ecological deficit in the EU member nations which is consistent with the statistical findings that reveals a reducing effect of ecological deficit on bio-economy. The study recommends for bio-economic governance reflecting effective bio-economic policies towards the preservation and optimal utilization of ecological resources of croplands, grazing land, forestry, marine, built-up land and forest land for the absorption of carbon footprints due to socio-economic activities among the EU member nations for smooth transition to bio-economy. Also, there is an urgent need to establish strict biocapacity thresholds and Footprint Accounting Metrics (FAM) that ensure the EU Bioeconomy operates within absolute ecological limits, prioritizing resource efficiency, cascading biomass use and absolute consumption reduction.

Key Words: Bio-economy, Ecological footprints, carbon footprints, ecological research, Bio-capacity, Bio-agriculture.

Introduction

The term bio-economy refers to the knowledge based production and effective utilization of biological resources to provide manufactured products, processes and services across economic sectors within the framework of a sustainable economic system (World Economic Forum WEF, 2016). The aspect of bio-economy also refers to the production of goods and services using renewable biological resources (i.e. solar, wind, land, biomass, etc.) supported by innovative and biotechnologies aiming to transitioning from fossil-based to a bio-based economy (WEF, 2016).

The field of bio-economy fosters technological breakthroughs that permeate all inclusive sectors such as; agriculture and food production, energy, industrial application, chemical industry, healthcare industry and paper production amongst others. However, the field of bio-economy is challenged by some global threats hampering its progress which includes; climate change, food security, loss of biodiversity and rural poverty amongst others (EC, 2018).

The adoption of bio-economy gains an increased attention across the globe in the face of geopolitical tensions, environmental pollution, climate change, biodiversity loss and due to potential economic opportunities presented in developing biotechnology (Frow, et al., 2009). This economic advancement has spurred many countries, including the (E.U) member states to actively partake in developmental projects towards the acceleration of transition to bio-economy (Staffas et al. 2013). However, the (E.U) member nations are quite distinct, in terms of ecology, technological advancements, and economic policies, which serves as precursors in determining the approach to bio-economy. Ecology significantly influence the progress of bio-economy irrespective of region, technology and economic policies. This is because governments that value the determinants of bio-economy more essentially ecological footprints of a given nation, emphasizes on policies towards salvaging and improving the ecological system as the key to bio-governance. Ecological footprint of a given nation determines how dependent humans are on the natural resources. In essence, it is a measure that indicates how much resources from the environment are required to support a specific way of life, businesses and all economic activities. Furthermore ecological footprints estimates the biologically productive land, sea and forest areas that are needed to provide the renewable resources that a given population consumes and the procedure of waste absorption generated during consumption processes (Jiang et al. 2021).

Activities in the bio-economic sectors are especially reliant on a healthy ecological system to ensure a sustained availability of natural resources demands needed for economic activities. Moreover, ecological footprints measures the biological requirements for productive activities (bio-economy) such as;

i. Croplands for food production
ii. Grazing land for animal production
iii. Forest areas for the production of timber and other wood products
iv. Marine areas for fishery and other blue economic activities
v. Built-up land for housing and infrastructure
vi. Forest land needed for the absorption of carbon dioxide emissions from energy consumption

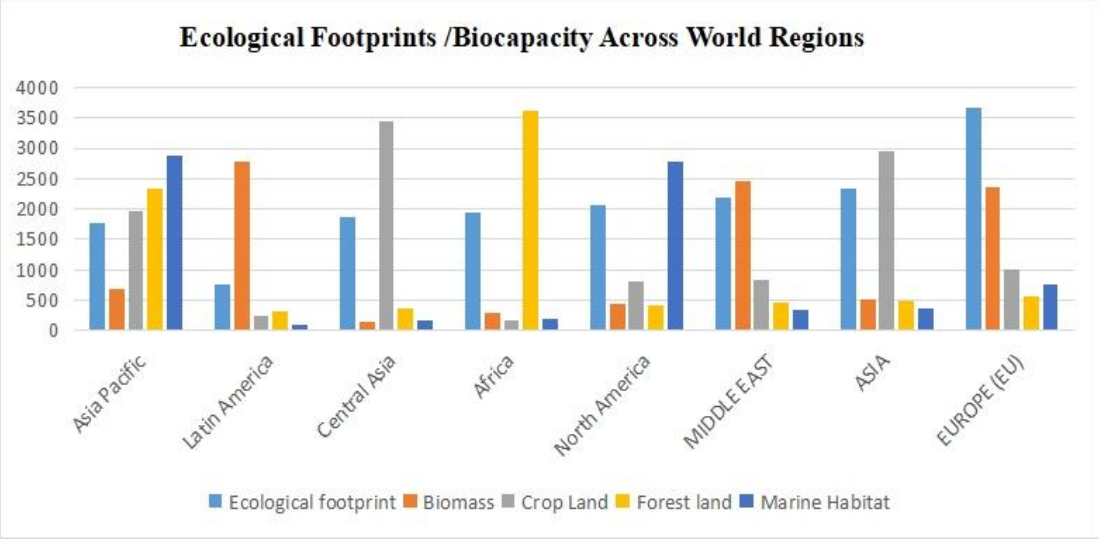
Furthermore, Ecological Footprint (EF) can said to be a metric computed by the Global Footprint

Network (GFN) and used to determine the impact humans are having on the environment of a given nation. More so, EF measures the natural resources humans are consuming in the environment through activities such as manufacturing, mining, fishing, farming and forestry. Especially when considered alongside complementary metrics such as bio capacity, ecological footprint provide an insight to inhabitants on their impact on the planet, guide countries in improving sustainability and well-being and provide the requisite information to leaders in allocating funding for public projects. Ecological footprint is quantified alongside bio capacity to establish a supply and demand based environmental accounting system. The supply of natural resources (bio-capacity) is compared to the demand for those resources (the footprint) to determine if the environment is capable of sustaining current level of resource consumption. Both ecological footprints and bio-capacity are expressed in 'per capita' values (i.e. per head) using global hectares (gha) as the unit.

The (E.U) member nations are quite distinct in ecological structure such as; (geography, natural endowments and biodiversity), technological advancements and economic policies, which serves as precursors in determining the approach to bio-economy. For instance, in Finland, availability of bio based resources in the form of forests plays a significant role, while in The Netherlands such resources are largely absent. In the later, product development in terms of chemical processing industry, green economy and conservation services plays a larger role in driving the transition to bio-economy. Although, E.U member countries, to some extent have distinct ecology, it appeared they have certain similarities in transitional approach to bio-economy (Bennett, 2012).

According to Global Footprint Networks (GFN, 2023), the comparison for ecological footprints and bio-capacity for the EU nations and other world regions in Figure 1, shows significant variations with former exceeding the later to a larger extent in the EU nations thereby influencing the transition to bio-economy (EU, 2023). It can be observed from the table that the figures for bio-capacity components of cropland, forestry, marine habitat and biomass are below that of ecological footprints for the EU nations contrary to what is observed in other world regions. The rapid depletion of bio-capacity components in the EU nations as against its ecological footprints hampers Bioeconomy due to inadequacy of natural endowments for economic purposes.

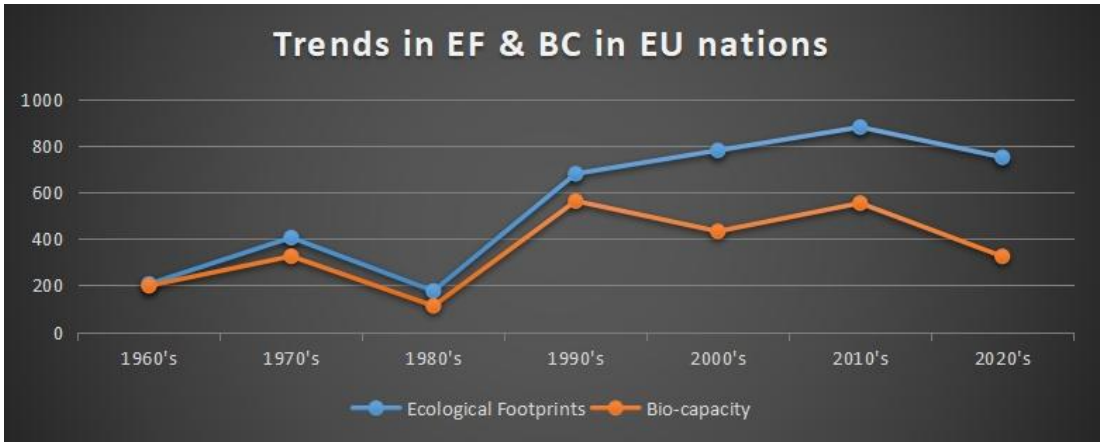
Figure 1: Ecological Footprints and Bio capacity across world regions



Source: Global Footprint Network (GFN, 2026)

The comparison of ecological footprint and bio-capacity is meaningless without the consideration of bio-capacity reserves towards the transition to a sustainable bio-economy. If a given population's ecological footprints exceeds its bio-capacity, that population has an ecological deficit. This means that the populations demand for natural resources exceeds its supply leading to resource shortages such as; basic food and shelter, higher prices, elevated levels of air, water and soil pollution. Conversely, if the bio-capacity of a given population exceeds its ecological footprints, it has an ecological reserve, meaning it can support the existing population at its current level of consumption with less problem. Therefore maintaining an ecological footprint below bio-capacity is a necessary condition for the sustainability of humanity and a vibrant bio-economy (Huang et al. 2020). A recent reports from the European Environmental Agency (EEA, 2022) indicates that the total ecological footprints for the EU member states is more than twice its bio capacity. Meaning that the regions total demand for ecological goods and services greatly exceeds the capacity of its eco-system to produce useful biological products and absorbs carbon waste. Such a large ecological deficit is detrimental to the environment as well as transition to bio-economy.

Figure 2: Trends in Ecological foot print and bio-capacity in EU nations (1990s-2020s)



Source: European Environmental Agency (EEA, 2026)

Depicted the trends in ecological footprints and bio-capacity in Figure 2, it appeared that the EU member states has a significant rise in EF rapidly during the 1960s and 1970s, respectively. Based on the figure, the EF remained relatively constant since the 1980s, increases in the late 1980s to mid-1990s and made a slightly increasing steady rate to mid-2010s and decreases slightly in 2020s. Over the observed same period, the regions total bio-capacity increased only slightly, meaning that, overall, between the 1960s and 2020s the ecological deficits in the region increased, with the ecological footprint now being more than twice its bio-capacity. This trend significantly hampers the transition to bio-economy in the EU member states.

While the term bio-economy appeared to have been utilized in the EU since the early 2000s, it was in the mid of that same decade it entered into policy networks in the European sphere (European Commission, 2012). However, the foundation of bio-economy originates from the earlier strategic agendas of the European Commission (EC), including the White Paper of 1993 that highlighted the need for a non-physical, knowledge-based investments, and the roles of ecology and biotechnology for innovation and growth (European Commission, 1993). The Lisbon Agenda in 2000 called for global leadership in the knowledge-based economy to secure competitiveness and economic growth, whereas,

in 2002, the EC stated that the life sciences and biotechnology are probably the most promising of the frontier technologies‖ with high capacity to contribute to the achievement of the Lisbon Agenda objectives (European Commission, 2002). These two events helped establish the knowledge-based bio-economy in European policy networks.

This study aimed to quantify or ascertain the level of dependency of E.U member nations on its available environmental resources. Moreover, the study aimed at examining the relevance of biological productive resources (i.e. Bio-capacity: such as; land, sea, forest, and solar) towards fostering biological based economy among the E.U member states in the presence of effective bio-governance.

Statement of the Problem

The European Union (EU) is rapidly transitioning towards a circular Bioeconomy to achieve the European Green Deal (EGD) objectives, aiming to replace the fossil-based energy sources with renewable biological resources. This shift is intended to reduce greenhouse gas emissions, foster rural development and promote a sustainable economic model across the EU member states. However, the rapid expansion of the EU Bioeconomy is driving an unsustainable increase in the region's ecological footprints and bio capacity, creating a resource-demand paradox. While replacing fossil fuels with biomass (i.e. forestry, crops, and marine resources) reduces carbon emissions, it drastically escalates the pressure on terrestrial and aquatic ecosystems. Hence, the EU current consumption patterns requires biomass production level that outstrip the regenerative capacity of its regional ecosystems. These imbalances manifests in the forms of land use competition, footprint displacement and ecological degradation, thereby undermining the EU biodiversity strategy for 2030.

Consequently, if unaddressed, the unchecked growth of the Bioeconomy will cause the EU to outgrow its planetary boundaries. Instead of achieving true sustainability, the region risks trading a carbon crisis for a biodiversity and biocapacity crisis. The aforementioned problem would compromise the EU's climate neutrality goals, and deepen global ecological inequalities.

Research Questions

These Questions were raised following the background and statement of the problem:

i. What is the effect of ecological footprint on bio economy in a sample of EU member states?
ii. What is the effect of carbon footprint on bio economy in a sample of EU member states?
iii. Does carbon foot print have any role on the nexus between ecological foot print and bio economy in a sample of EU member states?
iv. What is the effect of bio capacity on bio economy in a sample of EU member states?
v. What is the effect of ecological reserve on bio economy in a sample of EU member states?

Objectives of the Study

Specifically, this study aims to:

i. Examine the effect of ecological footprint on bio economy in a sample of EU member states
ii. Examine the effect of carbon footprint on bio economy in a sample of EU member states
iii. Investigate the role of carbon footprint on the nexus between ecological footprint and bio economy in a sample of EU member states
iv. Assess the effect of bio-capacity on bio economy in a sample of EU member states
v. Examine the effect of ecological reserve on bio economy in a sample of EU member states

Scope of the Study

The study assesses the socio-economic determinants of bio economy in selected EU member states with a specific emphasis on ecological foot prints and bio capacity for the period of 2019 to 2023 while adopting the quantification techniques of Ecological Footprint Accounting (EFA) in order to estimate EFP, BCP, CFP and BRD, respectively across the sampled member nations of the EU. The rationale behind the chosen time-range and adopted technique is to measure the resource dimension of the human socio-economic development (bio-economy) by comparing the demands of humans placed on earth's resource (i.e. biological productive lands, forest, and marine areas that provides regeneration) to the amount of eco-system availability and the capacity for generated waste absorption which experiences rapid changes during the study period. It is in light of the foregoing that this study further employed the Panel Pooled Ordinary Least Square (PPOLS) regression estimation technique to investigate the determinants of bio-economy among the EU member nations sampling ten most dependent EU member nations on natural resources for socio-economic activities as measured by ecological footprints for the most recent half decade (i.e. 2019-2023). This technique is carried out to determine the transition to bio-economy across EU member nation's cross-sections over a given period of five (5) years. The rationale for sampling EU member nations with highest dependency ratio on ecology is that they determine the level of ecological reserve or deficit (overshoot) for the EU region which is a necessary determinant for bio economy. Moreover, these selected EU member nations are sampled to determine the carbon footprint of the EU region which is also a determinant of bio-economy in the region. This study is arranged in five sections: introduction, literature review, methodology, results and discussions and conclusions.

Significance of the Study

The socio-economic activities of Humans relies on ecology products and services including resources, waste absorptive capacity, and space to host urban infrastructure for effective transition to bio-economy, irrespective of regions across the globe. Environmental changes such as deforestation, collapsing fisheries, and carbon dioxide (CO_2) accumulation in the atmosphere indicate that human demand on such products for socio-economic purposes may well have exceeded the regenerative and absorptive capacity of the biosphere. Careful assessment of human interaction with the ecology is essential to ensure optimal and efficient utilization of such products and services, thus, providing the necessities for effective transition to bio-economy. This study is timely and significant to EU member nations in the following ways. First, by adopting the metrics of EU National Footprint Accounts (NFA) of the Global Footprint Network (GFN), the study exposes the reality of ecological status in its original estimates in the EU member nation by assessing the current and historical trend in ecological supply and demand. This provides a basis for setting goals, identifying options for action, and tracking progress toward stated goals such as effective transition to bio-economy in the EU member states. Second, due to rapid depletion of ecological resources in the EU region, it is imperative to consider the rate of dependency of EU member nations on environmental requirements for an effective decision making. This can only be achieved by obtaining a verified statistical evidence like the one conducted in this study. Third, socio-economic activities in the bio-economic sector are especially reliant on a healthy ecological system to ensure a sustained availability of natural resources demands for forestry, marine, built-up land etc. for an effective transition to bio-economy. This study through estimated variables and discussions of findings provides the need for the reservation and optimal depletion of ecological resources. The statistical results obtained can serve as an informative tool for stakeholders of relevant authorities in the EU region for effective policy formulation and execution.

LITERATURE REVIEW

To acknowledge the significance of existing studies and for the purpose of timely contribution to literature, numerous studies on bio-economic governance and ecology were critically reviewed. For example, Galli (2023) investigate the resource dependence and carbon emissions of the EU-27's food systems from 2004 to 2014 via an ecological footprint (EF)-extended multi-regional input–output approach, accounting for demand and supply (including trade), and considering multiple externalities. Food contributes towards almost a third of the region's EF, and appropriates over half of its bio-capacity. Average reliance on bio-capacity within national borders decreased, while reliance on intra-EU bio-capacity increased; yet a quarter of the bio-capacity for food consumption originates from non-EU countries. Despite a reduction in both total EF and food EF over the study period, EU-27 residents demand more from nature than the region's ecosystems can regenerate highlighting the need for new or strengthened food and trade policies to enable a transformation to sustainable EU food systems.

Maksymiv et al. (2021) analyzes approaches to understanding the concept of the bio economy in highly cited journals, and bio economy strategies in associations of countries (the OECD and EU) and at the national level. Strategic challenges for sustainable bio economy governance are identified and an understanding of this concept is presented. The main aims, such as decoupling, the use of biotechnology, the use of sustainable biomass in the production process, and a high level of corporate social responsibility, are proposed for the identification of industries related to the bio economy. Specific goal achievement within the bio economy strategy and possible risks of conflict between SDGs are presented in the model. The bio economy should be considered a tool for achieving SDGs; the most relevant being 2, 3, 7, 9, 12, and 13–15. However, the achievement of bio economy goals can lead to a conflict between SDGs in practice. Therefore, this aspect must be taken into account at the stage of developing bio economy strategy and regulated in governance, to prevent conflicts between SDGs and to involve citizens and stakeholders in participating consciously in this process.

Also, Dietz et al. (2018) assesses bio-economic strategies in the context of the global Sustainable Development Goals (SDGs). Its theoretical framework distinguishes between four pathways of bio economic developments. The extent to which bio economic developments along these pathways lead to increased sustainability depends on the creation of effective governance mechanisms. The authors distinguish between enabling governance and constraining governance as the two fundamental political challenges in setting up an effective governance framework for a sustainable bio economy. Furthermore, the study laid out a taxonomy of political support measures (enabling governance) and regulatory tools (constraining governance) that states can use to confront these two political challenges. Guided by this theoretical framework, the study conduct a qualitative content analysis of 41 national bio-economy strategies to provide systematic answers to the question of how well designed the individual national bio economy strategies are to ensure the rise of a sustainable bio economy.

Also, Bosman and Rotmans (2016) We investigated the similarities and differences in the transition process and governance strategies with respect to the transition towards a bio economy in both countries, using transition management as an evaluative lens. The research method involved comparative qualitative case study analysis through action research. We found that the governance approach in The Netherlands focusses on co-creating a long-term vision that informs for short-term action, on facilitating bottom-up regional clusters and promoting radical innovation through cooperation between vested players and frontrunners. Finland adopts a more traditional, top-down governance strategy focusing on the shorter-term economic opportunities and incremental innovation that keep the overall structure of existing industries intact. We conclude that the Dutch government acts as a facilitator, while the Finnish government acts more as a director of the transition.

Furthermore, Mc Cormick and Kautto (2013) conducted a study that provides an overview of the bio-economy in Europe, examining it from a policy framework and concept perspective. The role of bioenergy in the bio-economy is discussed particularly through biofuels for transport and bio refineries. The study finds that the definitions of the bio economy are evolving and vary depending on the actor, but display similarities such as the emphasis on economic output and a broad, cross-sectoral focus. While there is great optimism about the benefits and opportunities associated with developing an advanced bio economy in Europe, significant risks and trade-offs are also expressed. Furthermore, the bio economy concept has been criticized for presenting a technical fix and pre-empting alternative visions. To advance a competitive and sustainable bio economy, this paper calls for attention on two important themes: participatory governance that engages the general public and key stakeholders in an open and informed dialogue as well as a commitment by government and industry to innovation that drives concerted efforts on sustainable development of the bio economy.

Moreover, Staffas et al. (2013) presented a comparative overview of the strategies and policies for developing a bio economy-in the EU, USA, Canada, Sweden, Finland, Germany and Australia. The documents analyzed are in most cases national strategies or policies. The structures and aims of these documents vary and the analysis is further complicated by the terms "bio economy" and "bio-based economy" having as yet no clear definition, a point which is discussed in some depth in this article. In the documents analyzed, strategies and policies on how to promote the bio economy are often presented based on the prerequisites of the country in focus; the need for increased research, development and demonstrations in the area is thus particularly stressed. The main emphasis is often to enhance the economy of a nation and provide new employment and business possibilities, whereas the aspects of sustainability and resource availability are addressed only to a limited extent in many of the documents.

In addition, Besi de Matteo and Mc. Cormick Kes (2015) employed a meta-analytical framework to examine the national, regional, and industrial perspectives on the bio-based economy in Europe. The analysis shows that a common direction for the bio economy, based on research and technological innovation in the various applications of biotechnology, is developing in Europe. It highlights the important role that the regional level will play in facilitating collaborations between industries and research institutions needed to foster innovation and optimize the use of biomass. The analysis also identifies that the development of European bio-based product markets are needed for bio economy expansion. However, the transition needs to have a lifecycle perspective in order to ensure that an economy founded on biomass is sustainable and equitable.

Gaps in the Literature

Based on critical assessment of extant literature on bio-economy an ecological footprint in the EU member states, numerous gaps have been uncovered with regards to theories, methods of data collection, presentation, and analysis, variable adoption and modelling techniques. This can be explained as follows:

1. **Variable Gaps**: evidently, most studies did not consider the role of carbon footprints in transition to bio-economy within the EU member states. Carbon footprints should be examined alongside ecological footprints when determining the transition to bio-economy, this is because as the population exhaust ecological resources for economic purposes, the bye-product of such activities involves pollution of various forms, which also requires effective management for socio-economic progress. The literature did not consider variable interaction in their modelling when estimating bio-economy, this study interacted ecological footprint and carbon footprint as an additional independent variable in its modelling. Ecological reserve is the difference between bio-

capacity and ecological footprints (i.e. demand-supply of ecological products and services). Ecological reserve/deficit has the potentiality of determining the transition to bio-economy among the EU member states, but it has not been considered by the literature.

2. **Methodological Gaps:** most of the studies reviewed did not consider empirical findings based on cause and effect relationship among estimated variables of interest. They did not consider examining bio-economy and its determinants on a cross-section of EU member nations over a given period of time (i.e. panel data analysis) in the most recent period of 2019-2023. The literature did not adopt the partial derivative technique in computing the marginal effect of one variable on the other given the range of values of other related variables. The reviewed literature did not consider modelling their selected variables in an econometric functional format such as the panel ARDL, unit root test and panel ECM models as clearly specified in this study.
3. **Theoretical Gaps:** theories are mostly reviewed to explain and serve as a basis for a given study. The reviewed literature did not consider a specific theoretical underpinning as its framework. This study adopted the Bio-economic theory of Aihua Pan in (2023).

METHODOLOGY

This sub-section entails the theoretical framework in which the study is based upon with the aim of assessing the determinants of bio-economy and its governance among the EU member nations. It also contains modelling, methods of data collection and analysis.

Theoretical Framework

This study is structured upon the bio-economic theory as coined by Aihua Pan in (2023). The recent Pan's Bio-economic theory refers to the new theories of bio-economy that the author has created by applying the ideas and approaches of life sciences Political ideas, and medicine in economics and social issues. The bio-economic theory comprises of; Bio-economics, Ecology, theory of information carrier of life, Econo-genology, social-genology, theory of life capital, theory of biological reconstruction of asset, triad theory, theory of asymmetric management information, medical model of stock market and corporate theory of state all aimed at strategizing the utilization of natural endowments towards economic prosperity (Pan, 2023).

Data Sourcing and Modelling

To assess the determinants of bio-economy within the EU member nations with highest dependency ratio on ecology, this study explored the official website of Global Footprint Network (GFN, 2023) under the national footprints and bio capacity accounts (1961-2023) and obtained a readily available data for the variables of the study (i.e. ecological footprints, bio-capacity, carbon footprint, ecological reserve / deficit). Data can be accessed via: https://data,footprintnetwork.org

However, data for bio-economy is obtained by adopting Bio-agriculture as one of the strategies of bio-economy as proxy. Bio-agriculture is a farming technique that aimed at attaining a balance between the physical, chemical nutrients and biological facets of the soil aided by improved organic carbon content. The rationale for adopting this highly relevant component as proxy is that bio-agriculture as one of the bio economic strategies exhibits a high sense of environmental quality, soil quality improvement by enhancing its structure, fertility and the presence of beneficial micro-organisms that supports biodiversity. Moreover, agriculture is among the constituents of ecology which supports the socio-economic lives of people living in a given nation, hence, has a direct linkage to ecological footprints which is considered as the variable of interest in this study.

Data for the recent past decade of (2014-2023) was adopted.

Table 3.1: Ecological Foot prints, Bio-agriculture (i.e. bio-economy), Bio-capacity, Carbon footprints, and Ecological Reserve/Deficit, at EU regional level, 2019 (gha/ oc)

Nations	B. Econ	EFP	CFP	BCP	ER / D (BCP-EFP)
France	22.4	61.3	3.77	30.4	(-30.9)
Germany	11.09	82.6	5.19	63.8	(-18.8)
Italy	8.24	58.8	3.15	40.5	(-18.3)
Poland	6.62	38.1	3.48	40.7	2.6
Netherlands	4.49	16.4	2.44	15.2	(-1.2)
Spain	3.70	43.9	3.94	38.2	(-5.7)
Romania	3.82	21.5	1.69	15.7	(-5.8)
Portugal	3.14	10.6	2.38	21.3	10.7
Belgium	3.38	10.4	1.39	0.81	(-9.59)
Czech Rep.	3.68	10.2	1.21	0.32	(-9.88)
Net Total	**73.7**	**353.8**	**28.64**	**266.93**	**(-86.57)**

Source: EU National Footprint Accounts 2019, of Global Footprint Network (GFN)

Table 3.2: Ecological Foot prints, Bio-agriculture (i.e. bio-economy), Bio-capacity, Carbon footprints, and Ecological Reserve/Deficit, at EU regional level, 2020 (gha/ oc)

Nations	B. Econ	EFP	CFP	BCP	E.R / D (BCP-EFP)
France	24.32	13.0	3.85	11.2	(-1.8)
Germany	15.30	5.2	0.82	4.3	(-0.9)
Italy	8.55	1.0	0.35	0.6	(-0.4)
Poland	7.65	1.8	2.98	1.9	(0.1)
Netherlands	7.19	2.4	2.49	2.6	0.2
Spain	4.69	3.7	0.86	2.1	(-1.6)
Romania	3.93	2.3	1.54	2.2	(-0.1)
Portugal	3.87	1.2	2.38	1.4	(-0.2)
Belgium	3.59	1.1	2.07	0.7	(-0.4)
Czech Rep.	3.54	2.6	1.39	0.8	(-1.8)
Net Total	**86.2**	**34.3**	**18.73**	**27.8**	**(-7.3)**

Source: EU National Footprint Accounts 2020, of Global Footprint Network (GFN)

Table 3.3: Ecological Foot prints, Bio-agriculture (i.e. bio-economy), Bio-capacity, Carbon footprints, and Ecological Reserve/Deficit, at EU regional level, 2021 (gha/ oc)

Nations	B. Econ	EFP	CFP	BCP	E.R / D (BCP-EFP)
France	37.9	33.2	2.12	32.1	(-0.1)
Germany	9.3	35.3	3.87	55.7	20.4
Italy	15.3	25.1	1.21	41.7	16.6
Poland	8.6	11.3	1.44	16.3	5.0
Netherlands	31.9	0.92	2.91	38.1	37.18

Nations	B. Econ	EFP	CFP	BCP	E.R / D (BCP-EFP)
Spain	14.1	20.7	0.82	17.3	(-3.2)
Romania	20.2	8.2	0.11	27.4	19.2
Portugal	20.6	7.5	1.39	0.92	(-6.58)
Belgium	-2.6	6.3	0.42	0.67	(-5.63)
Czech Rep.	-5.9	6.8	0.81	0.68	(-6.12
Net Total	**151.4**	**155.32**	**15.1**	**230.87**	**75.55**

Source: EU National Footprint Accounts 2021, of Global Footprint Network (GFN)

Table 3.4: Ecological Foot prints, Bio-agriculture (i.e. bio-economy), Bio-capacity, Carbon footprints, and Ecological Reserve/Deficit, at EU regional level, 2022 (gha/ oc)

Nations	B. Econ	EFP	CFP	BCP	E.R / D (BCP-EFP)
France	12.09	11.2	3.12	12.1	0.9
Germany	11.9	4.3	0.92	3.2	-0.9
Italy	5.62	0.8	0.37	0.9	0.1
Poland	5.78	2.1	2.11	3.1	1.0
Netherlands	5.12	2.7	2.42	2.9	0.2
Spain	4.59	2.9	0.81	3.2	0.3
Romania	4.82	1.1	1.51	1.8	0.7
Portugal	4.38	0.9	2.31	1.9	1.0
Belgium	3.63	0.7	0.79	2.1	0.14
Czech Rep.	3.15	3.1	1.48	0.6	(-2.5)
Net Total	**61.08**	**29.8**	**15.84**	**31.8**	**1.84**

Source: EU National Footprint Accounts 2022, of Global Footprint Network (GFN)

Table 3.5: Ecological Foot prints, Bio-agriculture (i.e. bio-economy), Bio-capacity, Carbon footprints, and Ecological Reserve/Deficit, at EU regional level, 2023 (gha/ oc)

Nations	B. Econ	EFP	CFP	BCP	E.R / D (BCP-EFP)
France	11.7	12.7	2.52	6.3	(-6.4)
Germany	11.67	32.5	3.71	5.4	(-27.1)
Italy	7.38	27.5	6.21	8.5	(-19)
Poland	6.14	26.2	5.22	9.7	(-16.5)
Netherlands	5.04	20.6	3.91	6.4	(-14.2)
Spain	4.73	34.3	1.72	2.3	(-32.0)
Romania	4.97	10.7	0.97	6.2	(-4.5)
Portugal	3.52	11.9	0.32	7.8	(-4.1)
Belgium	2.44	12.2	1.63	3.1	(-9.1)
Czech Rep.	1.88	0.92	1.11	0.7	(-2.0)
Net total	**59.47**	**189.52**	**27.32**	**56.4**	**(-134.9)**

Source: EU National Footprint Accounts 2023, of Global Footprint Network (GFN)

Table 3.6: Summary of Data Aggregate for a Sample of 10 (EU) Member Nations

Year / Varib.	B. ECON	EFP	CFP	BCP	E. R/D
2019	73.7	353.8	28.64	266.93	(-86.57)
2020	86.2	34.3	18.73	27.8	(-7.3)
2021	151.4	155.32	15.1	230.87	75.55
2022	61.08	29.8	15.84	31.8	1.84
2023	59.47	189.52	27.32	56.4	(-134.9)

Source: Authors computations from data aggregates of EU (NFA, 2019-2023)

Following data sourcing and quantification for the selected variable of the study, the mathematical functional form of modelling can be specifies thus:

$$B.ECON = f(EFP, CFP, BCP, ER.D) \quad (3.1)$$

The definitions, measurements and sourcing for each of the specified variable in model (3.1) is summarized in sub-section 3.3.

Definitions and Measurements of Variables

Variable	Definition and Measurement
Ecological Footprint	**EFP:** this measures the appropriate bio-capacity expressed in global average bio-productive hectares across five distinct land uses (i.e. cropland, grazing land, fishing grounds, forest land and built-up land) in addition to one category of indirect demand for bio-capacity in the form of absorptive capacity for carbon dioxide (CO2). Measured in Population in millions global hectare per capita (gha/capita). Source: National footprints account 2023 of Global footprints network GFN
Bio-capacity	**BCP:** this is an aggregated measure of the available land area weighted by the respective area productivity. It represents the biosphere capacity to produce crops, animal's grazing land, timber products, as well as to absorb the carbon dioxide in forest. It also includes how much regenerative capacity is occupied by infrastructure (i.e. built-up land). In summary, the bio-capacity measures the capacity of the area of land and water to produce ecological services.
Carbon Footprint	**CFP:** The uptake land to accommodate the carbon footprint is the only ecological land use type included in the ecological footprint which is exclusively to absorbing waste product (CO2) from economic activities. In addition, it is the only land use type for which bio capacity is not explicitly defined.
Ecological Reserve / Deficit	**ER/D:** This is the difference between Ecological footprints (EFP) and Bio-capacity BCP in a given nation. When the EFP is greater than the BCP for a selected time period, this brings about ecological deficit or overshoot, conversely, is regarded as ecological reserve. In essence, an ecological deficit or overshoot occurs in cases of excessive natural resources extraction and waste generation which exceeds the ecosystem's ability to regenerate the extracted resources and absorb the generated waste. A global overshoot (at the planet level) leads to a depletion of the earth's life supporting natural capital and built-up waste.

Variable	Definition and Measurement
Bio-economy	**B. ECON:** A component or one of the strategies of bio-economy bio-agriculture is employed as a measure for bio-economy. The measure for bio-agriculture is Trade balance (net exports) of agri-food products (millions euro per annum) source: EU commission monitoring EU- Agri-food trade development 2014-2023.

Methods of Data Analysis

Following the specific objectives of this study, some requisite statistical methods of analysis were enumerated in this sub-section towards achieving these aims, such as:

Pre-estimation Tests

This study carefully conducted some pre-estimation tests by adopting the Augmented Dickey Fuller and Phillip Perron models respectively. This is aimed at verifying the stability and coherence of the employed variables over the given period of the study (i.e. 2019-2023) across the cross-sections of selected EU member nations. The pre-estimation test is performed before estimation of the study model (Panel ARDL-ECM) using the t-statistic on the following regression as proposed by (Kwiatkowski, Philip, Schmidt & Shin, 1992).

$$\Delta X_t = \alpha + \beta_t + \beta X_{t-1} + \sum_{i=1}^{k} \gamma i \Delta X_{t-i} + \varepsilon_t \quad (3.2)$$

the unit root (pre-estimation) test is conducted by testing the null hypothesis (H0) against the alternative hypothesis (H1) using the following set of equations:

H0: $\beta = 1$ (Presence of unit root)

H1: $-1 < \beta < 0$ (Stationary series)

The test statistic is expected to be negative and statistically significant at either 1%, 5% or 10% level of significance, it can then be concluded that variables are stationary hence the null hypothesis (H0) is rejected and vice versa.

Descriptive Statistics and Correlation Analysis

This statistical technique is aimed at describing the association of the selected variables of the study over a given period of review. It also depicts the range of values for each of the selected variables such as the minimum, average and maximum.

Bounds Testing to Cointegration

This statistical technique is employed to statistically examine the long-run relationship (cointegration) among the selected variables of study for the period under review.

Panel ARDL & ECM Estimates for Long and Short Run Models

The Autoregressive Distributed Lag (ARDL) and Error Correction Models (ECM) were employed to estimate the long run and short run coefficients of the selected variables among the cross- section of EU member nations over the period of (2019-2023), the significance and magnitude of their respective effects on the explained variable and the period of adjustment due to short-run distortions. Hence the econometric model for the study is specified thus:

$$B.\ ECON_{it} = \varphi_i + \beta_1 EFP_{it} + \beta_2 CFP_{it} + \beta_3 BCP_{it} + \beta_4 E.R/D_{it} + \mu_{it} \quad (3.3)$$

To statistically determine the short and long run effect of ecological footprints, carbon footprints, bio-capacity and ecological reserve/deficit on bio-economy, the Panel ARDL and ECM models are specified in 3.4 and 3.5 as follows:

$$\Delta \ln(\text{B. ECON})_t = \partial_0 + \partial_1 L(\text{B. ECON})_{t-1} + \partial_2 L(EFP)_{t-1} + \partial_3 L(\text{CFP})_{t-1} + \partial_4 L(\text{BCP})_{t-1} + \partial_5 L(E.R/D)_{t-1} + \sum_{i=1}^{n} \beta_i \Delta L(\text{B. ECON})_{t-i} + \sum_{i=0}^{m} \beta_2 \Delta L(EFP)_{t-i} + \sum_{i=0}^{h} \beta_3 \Delta L(\text{CFP})_{t-i} + \sum_{i=0}^{j} \beta_4 \Delta L(\text{BCP})_{t-i} + \sum_{i=0}^{k} \beta_5 (E.R/D)_{t-1} + e_t \quad (3.4)$$

The bounds test is conducted by testing the null hypothesis (H0) against the alternative hypothesis (H1) using the following equations:

$$H_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$$
$$H_1 \neq \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$$
$$\Delta \ln(\text{B. ECON})_t = \beta_0 + \sum_{i=1}^{n} \beta_i \Delta L(\text{B. ECON})_{t-i} + \sum_{i=0}^{m} \beta_2 \Delta L(EFP)_{t-i} + \sum_{i=0}^{h} \beta_3 \Delta L(\text{CFP})_{t-i} + \sum_{i=0}^{j} \beta_4 \Delta L(\text{BCP})_{t-i} + \sum_{i=0}^{k} \beta_5 (E.R/D)_{t-1} + \gamma_1 ECM_{t-1}\, \mu_t \quad (3.5)$$

Diagnostic Test

A series of diagnostic tests to ascertain the validity of estimated results were carried out. These includes: LM test for serial correlations, BPG test for Heteroskedasticity, RESET test for error specification and normality test for data stability, respectively.

Computations for Marginal Effects of Variables

This statistical technique is employed to estimate the periodic unit change in bio-economy (proxy by bio-agriculture) due to ecological footprints given different margins of carbon footprints in the sample of EU member nations over the given period of (2019-2023)

Following the econometric model specified in (3.3), the interaction of ecological footprint EFP and carbon footprint CFP can be included in model (3.6) as follows:

$$B.\ ECON_{it} = \varphi_i + \beta_1 EFP_{it} + \beta_2 CFP_{it} + \beta_3 (EFP * CFP)_{it} + \beta_4 BCP_{it} + \beta_5 E.R/D_{it} + \mu_{it} \quad (3.6)$$

From equation (3.6), the marginal effect of ecological footprints on bio-economy at a given values of carbon footprints is obtained by taking the partial derivative of the equation in (3.7) as follows:

$$\frac{\partial B.ECON_{it}}{\partial EFP_{it}} = \beta_1 + \beta_3 CFP_{it} \quad (3.7)$$

RESULTS AND DISCUSSIONS

This sub-section presents and discusses the results obtained from the statistical computations conducted in this study.

Summary of Descriptive Statistics & Correlation Analysis

Prior to the analysis of data, the study conducted the descriptive statistics test and correlation analysis for the variables and presented the results in a summary form in Table 1. The results show the average (mean) value for bio-economy B.ECON (bio-agriculture) as 21.11787. In addition, the average for ecological footprints EFP and carbon footprints CFP stands at 75.38182 and 4.129874, respectively. Also, the results indicates that the average rate of bio-capacity BCP stands at (39.23560) and ecological reserve stands at 35.96462. Moreover, the standard deviation for bio-economy (i.e. 19.58609) and ecological footprints (i.e. 22.2768) showed a wider variation which indicates that the variables are quite dispersed around their respective means. Furthermore, the standard deviations for carbon footprints (i.e. 1.033241) and bio-capacity (i.e. 0.921936) show less dispersions from average indicating that the variables are quite close around their respective means**.**

Table 1: Descriptive Statistics and Correlation Analysis

Variables	$B.ECON$	EFP	CFP	BCP	$E.R/D$
Mean	21.11787	75.38182	4.129874	39.2356	35.96462
Min	7.08044	2.3543	1.24262	10.266667	16.382224
Max	62.38949	87.5456	24.950987	63.24167	78.8355
Std. Dev.	19.58609	22.2768	1.033241	0.921936	12.867134
Obs.	**50**	**50**	**50**	**50**	**50**

Correlation Analysis					
$B.ECON$	1.000000				
EFP	-0.757637	1.000000			
CFP	-0.653102	0.962933	1.000000		
BCP	0.053957	-0.354090	-0.333809	1.000000	
$E.R/D$	0.184929	-0.309948	-0.241427	0.455070	1.000000

Source: Author's computations in 2026

Furthermore, this study computed a correlation matrix of the variables employed and reported the results in the lower panel of Table 1. The results indicate that there is high positive correlation between the pairs- ecological footprint EFP and carbon footprint CFP (i.e. 0.962933). This results strengthen the view that the exploitation of natural resources for socio-economic activities by individual members of the society tallies with greenhouse emissions from same activities.

In addition, the correlation results indicate a week positive correlation between the pairs- bio-economy B. ECON and ecological reserve E. R/D (i.e. 0.184929), ecological reserve E. R/D and bio-capacity

BCP (i.e. 0.455070) and bio-capacity and bio-economy, respectively (i.e. 0.053957). Furthermore, there is a high negative correlation between the pairs- ecological footprint EFP and bio-economy (i.e. -0.757637), and carbon footprint CFP and bio-economy (i.e. -0.653102), respectively. However, there is a weak negative association between the pairs- bio-capacity BCP and carbon footprint (i.e. -0.333809), bio-capacity BCP and ecological footprints EFP (i.e. -0.354090), ecological reserve E. R/D and ecological footprint (i.e. -0.309948) and ecological reserve E. R/D and carbon footprint CFP (i.e. -0.241427).

Results of Pre-estimation (Stationarity) Tests

Before the analysis of data, the variables were tested for stationarity and coherence using the Augmented Dickey Fuller (ADF) and Philips Perron (PP) unit root tests, respectively. The results of the unit root tests reported in Table 2 indicate that bio-economy B.ECON (i.e. -3.018235) at first differential equation from the ADF test has no unit root at the 1% level of significance (see Appendices for test critical values). The values also show that ecological footprints EFP is stationary at level and integrated to order zero [I(0)] for the ADF test, and failed in the PP test.

Table 2: Results of Unit root Test

	ADF		**PP**		
Variables	Level	First Difference	Level	First Difference	Stationarity Status
$B.ECON$	----------	-3.018235***	----------	----------	I (1)
EFP	-2.077543**	----------	----------	----------	I (0)
CFP	---------	---------	---------	-1.090811*	I (1)
BCP	----------	--------	--------	-6.452886***	I (1)
$E.R/D$	-9.029709*	---------	----------	----------	I (1)

Source: Authors' computations in 2026. ***,**,* indicates significant level at 1%,5% and 10%.

Furthermore, carbon footprints with a value of (-1.090811) have the presence of a unit root at level I(0), but after taking the first difference, the variable became stationary at 10% level of significance and integrated to order one [I(1)] for the PP tests and failed in the ADF test, respectively. Also, bio-capacity BCP with a value of (-6.452886) for PP test is stationary at the 1% level and integrated to order one [I (1)]. Lastly, ecological reserve E. R/D with a value of (-9.029709) for ADF test is stationary at 10% level of significance and integrated to order one [I (1)]. The order of integration of the variables, which is a mixture of [I (0)] and [I(1)] using both ADF and PP tests, provides justification for using ARDL-bounds test to cointegration.

Results of Bounds Testing to Cointegration

In line with the aim of the study, the long run linear relationship (cointegration) is computed among the variables of the study and the results is presented in Table 3 as follows:

Table 3: Results of Bounds Test to Cointegration (ARDL Model)

Dependent Variable	Function	F-statistic
$B.ECON$	f(EFP, CFP, BCP, E.RD)	9.5723***

Critical Value Bounds					
10%		5%		1%	
I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
2.81	3.03	3.56	4.13	6.29	6.71

Source: Author's computations in 2026. *** denotes a rejection of the null hypothesis of no cointegration at 1% level.

From Table 3, the computed F-statistic (9.5723) is statistically beyond the upper critical bound I (1) with a value of (6.71) at 1% level of significance. The results suggest the existence of long-run linear relationship (cointegration) among the variables in the estimated ARDL model.

Results of Estimations of the Short Run and Long Run Panel ARDL Model

Given the confirmation of cointegration among the variables, the ARDL-ECM model was estimated, taking into consideration the optimal lag length (3,4,0,4) as suggested by the Akaike information criterion. Results for the long run and short run models are presented in Table 4. According to the long run results as shown in Panel A of the Table, ecological footprints EFP with value (2.6432) has a positive and insignificant effect on bio-economy B. ECON in the EU member nations. Contrary to the short-run results as reported in panel B of the Table which show that ecological footprints EFP (-1.3806) has a negative and significant effect on bio-economy B. ECON in the EU member nations. This result is consistent with the findings of extant literature (see Galli, 2023)

Table 4: Results of Panel ARDL-ECM Estimations

Panel A: Long-run Coefficients (Dependent Variable is $B.ECON$)				
Variable	Coefficient	Std. Error	T. ratio	Prob.
EFP	2.6432	7.1207	0.3712	0.2400
CFP	-3.4678	4.4512	-0.7791	0.0681
$EFP * CFP$	-1.1295	3.7659	-0.2999	0.0051
BCP	5.3404	6.7392	0.7924	0.0071
$E.R/D$	-0.0064	0.0276	-0.2319	0.0067
C	4.8602	3.3464	1.4523	0.0000
Panel B: Short-run Coefficients (Dependent Variable is $\Delta B.ECON$)				
$\Delta(EFP)$	-1.3806	4.0707	-0.3391	0.0010
$\Delta(CFP)$	-0.0359	0.1050	-0.3419	0.7344
ECT_{t-1}	-0.7219	0.1350	-5.3474	0.0000

Source: Author's calculation in 2026. Δ is the first difference operator.

In addition, the result suggest that carbon footprint with a value of (-1.1259) in the long run has a negative and significant effect on domestic bio-economy among the EU member nations. In essence, the increment of carbon emissions significantly retards the transition to bio-economy with about 1.1259 % at the 10% level of significance. Furthermore, bio-capacity BCP has a positive (5.3404) and significant effect on bio-economy in the long run. The findings is in line with previous studies conducted on the EU member nations (see Galli, 2023). Moreover, the results shows an ecological deficit of (-0.0064) with a statistical significant effect on bio-economy at 5% level of significance. The coefficient of the error correction term (i.e. -0.7219) lagged by one period (ECT_{-1}) is negative and statistically significant at the 1% level. This implies convergence to long run equilibrium in the event of disturbance in the short run. It also indicates that approximately, about 72.19% of the distortions in bio-economy in the EU member nations will be adjusted within a given one-year period.

Results of Diagnostic Test for the Panel ARDL-ECM Model

For reliability and validation of results earlier reported in 4, a diagnostic test for the ARDL-ECM models was conducted and reported in Table 5.

Table 5: Panel ARDL-ECM Model Diagnostic Tests

Test Statistic	Results
Serial Correlation:	0.6398[0.5347]
Heteroskedasticity:	1.1078[0.3829]
Functional Form: Reset F-stat.	0.5277[0.6016]
Normality: Jarque-Bera	0.3913[0.8222]

Source: Author's calculation in 2026. Values in parenthesis are probability values.

The diagnostic tests conducted examines serial correlation, heteroskedasticity and normality distribution problems associated with the model. The study employed the Breusch- Godfrey LM test in order to test for serial correlation. The results show that there is no serial correlation in the ARDL-ECM estimators since the ρ-value of (0.6398) is above 5% significance level. Furthermore, the Breusch-Pagan-Godfrey test was employed to ascertain if the random error terms are homoscedastic and it show by a ρ-value of (1.1078) which is above 5% level of significance, this implies that the error terms are homoscedastic. Also, the Jarque-Bera normality test was employed to test for normality in the error term and the results show a ρ-value of (0.3913), this implies that the residuals are normally distributed at 1% level. Lastly, the Ramsey Regression Equation Specification Error Test (RESET) was conducted to check for functional form, Mis-specification and variable omission for the ARDL-ECM models. The results show the ρ-value (0.5277) which is above 5%, and implies that the model is correctly specified in a linear form.

Marginal Effect Results

Table 6 presents the results of marginal effect of ecological footprint on bio-economy at different margins of carbon footprints.

Table 6: Marginal Effect of ecological foot prints on bio-economy at varying margins of carbon footprints

Variable	Coefficient	ρ. value	Mean	Min	Max
CFP	-3.4678	0.0003	75.3818	2.3543	87.5460
EFP	2.6432	0.0027	74.1298	1.2426	95.0987
$EFP * CFP$	-1.1259	0.0082	(-82.22)	(-0.007)	(-95.92)

Source: Author's calculation in 2026

Computations

Following the marginal effect model specified in (3.7) as follows:

$$\frac{\partial B.ECON_{it}}{\partial EFP_{it}} = \beta_1 + \beta_3 CFP_{it} \quad (3.7)$$

The values for the coefficients of ecological footprints EFP and that of its interaction with carbon footprint are substituted into (3.7). Moreover, the minimum, mean and maximum values of carbon footprints are substituted to obtain the marginal effect results. This can be done as follows:

Minimum values

$\beta_1 + \beta_3 CFP_{it}$

B1= 2.6432

B3=-1.1259

Minimum CFP=2.3543

2.6432 + (-1.1259) (2.3543)

2.6432 + (-2.6507)

= -0.0075

The results suggests that at minimum value of carbon footprints CFP (i.e. 2.3543), the marginal effect of ecological footprint EFP on Bioeconomy is -0.0075, suggesting that ecological footprints and carbon footprint has both direct and indirect effect on bio-economy in the EU member nations.

Maximum values

$\beta_1 + \beta_3 CFP_{it}$

B1= 2.6432

B3=-1.1259

Maximum CFP= 87.5456

2.6432 + (-1.1259) (87.5456)

2.6432 + (-98.5676)

= -95.9244

The results suggests that at maximum values of carbon footprint CFP (i.e. 87.5456), the marginal effect of ecological footprint on bio-economy is -95.9244, suggesting that both ecological foot print and

carbon footprint has a reducing effect on the transition to bio-economy in the EU member nations. In essence, the higher the rate of ecological footprints and carbon footprints, the lesser the components of ecology and biodiversity which supports Bioeconomy.

CONCLUSIONS AND RECOMMENDATIONS

Based on statistical indicators obtained from bio-economic determinants in the EU member states, it is evident that the features of its transition depends on ecological footprints, bio-capacity, ecological reserve/deficit and carbon footprints. Bio-agriculture as one of bio-economic strategies serves as a good estimator by responding appropriately to effects of bio-economic explanatory variables. By distinguishing the values of Ecological Footprint measure with the actual bio-productive capacity of the EU member states, it is possible to determine whether the region has ecological deficit (using more resources than it has) or it has ecological reserve. While in totaling Ecological Footprint, in the investigated period (2019-2023), a general increasing trend was noticed (justified by the increasing demand of resources in the economic development process), in total Bio capacity, as expression of the supply of renewable resources tends to appear below the demands for natural resources thereby resulting to ecological deficit. The study recommends for bio-economic governance reflecting effective bio-economic policies towards the preservation and optimal utilization of ecological resources of croplands, grazing land, forestry, marine, built-up land and forest land for the absorption of carbon footprints due to socio-economic activities among the EU member nations. Moreover, policy frameworks and scientific models must move beyond simply measuring carbon reduction. There is an urgent need to establish strict biocapacity thresholds and Footprint Accounting Metrics (FAM) that ensure the EU Bioeconomy operates within absolute ecological limits, prioritizing resource efficiency, cascading biomass use and absolute consumption reduction.

REFERENCES

Aihua, P. (2023). Bioeconomy: Theory and practice in the Bio economic industry. *Springer,* 2(3), 221-228.

Bosman, R., & Rotmans, J. (2016). Transition Governance towards a Bio economy: A Comparison of Finland and The Netherlands. *Sustainability* 2016, 8, 1017

Bennett, S.J. (2012). Using past transitions to inform scenarios for the future of renewable raw materials in the UK. *Energy Policy* 2012, 50, 95–108

De Besi, M. & McCormick, K. (2015). Towards a Bio economy in Europe: National, Regional and Industrial Strategies. *Sustainability* 2015, 7, 10461–10478.

Dietz, T. Jan, B. Janosch, F. & Joachim, V. (2018). Governance of the Bioeconomy: A Global Comparative Study of National Bioeconomy Strategies. *Sustainability*, 1 (2), 243-257.

European Commission (EC, 1993). Growth, Competitiveness, Employment: The Challenges and Ways forward into the 21st Century; White Paper, COM (93)700; *European Commission: Brussels, Belgium*, 1993. 13.

European Commission (EC, 2002). The Lisbon European Council: An Agenda of Economic and Social Renewal for Europe; European Commission: Brussels, Belgium, 2002.

European Commission (EC, 2018). Life Sciences and Biotechnology: A strategy for Europe; COM (2018)27; European Commission: Brussels, Belgium, 2018

European Commission (EC, 2012). Innovating for Sustainable Growth: A Bioeconomy for Europe; COM (2012) final; European Commission: Brussels, Belgium, 2012.

Frow, E., Ingram, D. Powell, W. Steer, D.; Vogel, J. & Yearley, S (2009). The politics of plants. Food Security. 2009, 1, 17–23

Herring, H.; & Roy, R. (2007). Technological innovation, energy efficient design and the rebound effect. *Tec novation* 2007, 27, 194–203

Kamm, & Kamm, (2004). Principles of bio refineries. Appl. Microbial. Biota. 2004, 64, 137–145

McCormick & Kautto (2013). The Bioeconomy in Europe: An Overview, Sustainability 2013, 5, 2589-2608; doi:10.3390/su5062589

Maksymiv, Y., Valentyna, Y. , Nadia, P., Iryna, H., Iryna, P. & Nazariy, P. (2021). Strategic Challenges for Sustainable Governance of the Bioeconomy: Preventing Conflict between SDGs. sustainability

Organization for Economic Cooperation and Development (OECD, 2020). The Bioeconomy to 2030: Designing a Policy Agenda, Scoping Document; *Organization for Economic Cooperation and Development*: Paris, France, 2020.

Pannicke, N., Gawel, E., Hagemann, N., Purkus, A. & Strunz, S. (2015). The political economy of fostering a wood-based Bioeconomy in Germany. Ger. J. Agric. Econ. 2015, 64, 224–243.

Pfau, S.; Hagens, J.; Dankbaar, B.; & Smits, A. (2014). Visions of Sustainability in Bioeconomy Research. *Sustainability*2014,6,1222–1249.

Pollack, (2013). A White House Promotes a Bioeconomy; New York Times, 26 April 2012. Available online: http://www.nytimes.com/2012/04/26/business/energy-environment/white-house-promotes- a-bioeconomy.html?_r=0 (accessed on 19 March 2013).

Purkus, A., Röder, M., Gawel, E., Thrän, D. & Thornley, P. (2015). Handling Uncertainty in Bioenergy Policy Design—A Case Study Analysis of UK and German Bioelectricity Policy Instruments. *Biomass Bioenergy* 2015, 79, 54–79

Smeets, E. T., A., van Berkum, S., Moorad, J.; van Meijl, H. & Woltjer, G. (2015). The impact of the rebound effect of the use of first generation biofuels in the EU on greenhouse gas emissions: A critical review. *Renew Sustain. Energy Rev.* 2015, 38, 393–403

Staffas, L., Gustavsson, M., & McCormick, K. (2013). Strategies and Policies for the Bioeconomy and Bio-based Economy: An analysis of official national approaches. Sustainability 2013,

VonBraun,J.;Birner,R.DesigningGlobalGovernanceforAgriculturalDevelopmentandFoodandNutrition Security. Rev. Dev. Econ. 2016, 21.

World Economic Forum (WEF, 2016).Global Risks Report,11th Edition. Available online: http://www3.weforum. org/docs/Media/TheGlobalRisksReport2016.pdf (accessed on 20 August 2016).