

Impact of Economic Activities on Forest Load Capacity in Nordic Countries

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Abstract

Aim of study: The study aims to test the Environmental Kuznets Curve (EKC) and Load Capacity Curve (LCC) hypotheses by analyzing how economic and environmental factors influence forest load carrying capacity (FLCC) in Nordic countries.

Area of study: This research focuses on the Nordic countries-Finland, Denmark, Norway, and Sweden-regions characterized by high forest coverage, advanced economies, and strong environmental policies.

Material and method: Using annual data from four Nordic countries for the period 2010–2021, the study employs the Panel ARDL method to analyze dynamic relationships between variables, and based on the Hausman test indicating homogeneity of long-run coefficients, the PMG estimator is applied.

Main results: The empirical results support the EKC and LCC hypotheses. Economic growth initially exerts a negative effect on forest load capacity but enhances environmental sustainability after a certain income threshold.

Research highlights: The study reveals that in Scandinavian countries, economic growth initially harms but eventually supports forest sustainability, while carbon intensity, agricultural expansion, and urbanization exert lasting environmental pressures on FLCC, highlighting the need for integrated and country-specific sustainability policies.

Keywords: Forest Load Capacity Curve (FLCC), Environmental Kuznets Curve (EKC), Economic Growth, Nordic Countries

İskandinav Ülkelerinde Ekonomik Faaliyetlerin Orman Yük Kapasitesi Üzerindeki Etkisi

Öz

Çalışmanın amacı: Bu araştırmanın amacı, İskandinav ülkelerinde ekonomik ve çevresel faktörlerin orman yük taşıma kapasitesi (FLCC) üzerindeki kısa ve uzun dönemli etkilerini inceleyerek Çevresel Kuznets Eğrisi (EKC) ve Yük Taşıma Kapasitesi Eğrisi (LCC) hipotezlerini test etmektir.

Çalışma alanı: Bu çalışma, çevresel sürdürülebilirlik açısından orman ekosistemlerinin kritik bir rol oynadığı İskandinav ülkeleri-Finlandiya, Danimarka, Norveç ve İsveç-üzerine odaklanmaktadır.

Materyal ve yöntem: 2010-2021 dönemine ait dört İskandinav ülkesinin yıllık verileriyle yapılan çalışmada, değişkenler arası dinamik ilişkiler Panel ARDL yöntemiyle incelenmiş ve Hausman testine göre uzun dönem katsayılarının homojenliği dikkate alınarak PMG tahminleyici kullanılmıştır.

Temel sonuçlar: Elde edilen bulgular, yüksek gelirli ülke bağlamında EKC ve LCC hipotezlerinin geçerli olduğunu ortaya koymaktadır. Ekonomik büyüme başlangıçta FLCC'yi olumsuz etkilerken, belirli bir gelir seviyesinin ardından çevresel sürdürülebilirliği artırmaktadır.

Araştırma vurguları: Çalışma, İskandinav ülkelerinde ekonomik büyümenin orman sürdürülebilirliğiyle başlangıçta olumsuz, uzun vadede ise olumlu etkiler yarattığını; karbon yoğunluğu, tarımsal genişleme ve şehirleşmenin ise FLCC üzerinde kalıcı çevresel baskılar oluşturduğunu ve ülkeye özgü sürdürülebilirlik politikalarının önemini ortaya koymaktadır.

Anahtar kelimeler: Orman Yük Kapasitesi Eğrisi, Çevresel Kuznets Eğrisi, Ekonomik Büyüme, İskandinav Ülkeleri



Introduction

Sustainable management of natural resources has become a critical global issue, particularly in balancing economic growth with environmental protection. The rapid industrialization process since the Industrial Revolution has intensified fossil fuel consumption, exacerbating environmental issues such as atmospheric pollution, climate change, and ecological degradation. Human activities have profoundly altered the Earth's natural systems, leading to what is described as the Anthropocene Epoch (Steffen et al., 2007). Anthropogenic pressures risk exceeding the sustainability boundaries of the planet, a phenomenon conceptualized as "Planetary Limits" (Rockström et al., 2009).

Deforestation represents one of the most significant dimensions of environmental degradation, accelerating due to industrialization, urbanization, agricultural expansion, and forestry activities. Global forest cover changes between 2000 and 2012 show a total loss of 2.3 million km² and a gain of only 0.8 million km², indicating that despite political interventions, deforestation continues at an alarming rate, particularly in tropical zones (Hansen et al., 2013). The key drivers of global deforestation have been classified into commodity-driven permanent deforestation (27%), shifting agriculture (24%), forestry activities (26%), fires (23%), and urbanization (0.6%), with forestry activities playing a significant role in planned cuttings and afforestation processes (Curtis et al., 2018).

Urbanization significantly impacts forest areas by contributing to biodiversity loss, ecosystem disruption, and reductions in carbon stocks (Seto et al., 2012). In Türkiye, urbanization has been found to increase environmental pollution (Ozatac et al., 2017; Katircioğlu & Katircioğlu, 2018). In Scandinavian countries, urbanization, agricultural expansion, and infrastructure development have played a substantial role in forest losses between 1992 and 2018 (Zhou et al., 2021). In the Nordic region, urban expansion reduces ecological carrying capacity, threatening long-term environmental sustainability (Hossain et al., 2024).

Agricultural expansion has also played a crucial role in deforestation. Between 1980

and 2000, more than 55% of newly cultivated agricultural land in the tropics was converted from intact forests, with an additional 28% from previously degraded forested areas (Gibbs et al., 2010). The increasing global demand for food and biofuels has further expanded agricultural areas, significantly contributing to tropical forest loss, especially in South America and Africa (Laurance et al., 2014). Agricultural expansion continues to be a major factor in deforestation, and balancing food security with environmental sustainability requires more integrated policies (Meyfroidt et al., 2018).

Urbanization, agricultural expansion, and forestry activities collectively contribute to environmental degradation, leading to biodiversity loss, soil erosion, and disruptions in the water cycle (FAO, 2020). Forest ecosystems are crucial in mitigating climate change through carbon sequestration and providing essential ecosystem services such as water regulation and habitat preservation (MEA, 2005). However, controlling deforestation has become increasingly complex due to economic globalization and industrial growth. Economic globalization accelerates land-use change, complicating efforts to achieve environmental sustainability (Lambin & Meyfroidt, 2011). Land-use changes driven by human activities pose severe threats to biodiversity and climate stability (Foley et al., 2001).

EKC hypothesis describes the relationship between economic growth and environmental quality. In the early stages of economic development, environmental degradation increases, but after reaching a certain income threshold, environmental conditions begin to improve as societies invest in cleaner technologies and sustainable policies (Grossman & Krueger, 1995; Pata & Tanrıover, 2023). Conversely, the LCC hypothesis evaluates environmental sustainability through the balance between economic activity and resource consumption, suggesting that excessive economic growth may surpass an ecosystem's ability to regenerate (Shahzad et al., 2024; Tiwari et al., 2024). Both hypotheses provide critical perspectives in assessing the impact of economic and environmental interactions on forest sustainability.

The Scandinavian countries—Finland, Denmark, Norway, and Sweden—possess significant forest cover, with forests accounting for 75% of Finland's total land area, 69% of Sweden's, 37% of Norway's, and 13% of Denmark's (Mattsson, 2016). Despite their emphasis on sustainable forestry policies, these nations have experienced substantial forest losses due to agricultural expansion, urbanization, and forestry activities (Zhou et al., 2021). Between 1992 and 2018, Sweden lost approximately 13008 km² of forest (-4%), Finland 5982 km² (-22%), Norway 5870 km² (-18%), and Denmark 717 km². The primary causes of these losses include increased agricultural land in Sweden (+29% in three decades) and urban expansion in Denmark (+70%), where most new settlements have been converted from agricultural land rather than forests (de Wit et al., 2020).

Economic growth and industrialization remain central factors influencing forest degradation. Sweden and Finland are among the world's largest producers of timber and paper, heavily exporting forest products despite their commitment to sustainable forestry principles (Pirnazarov & Sellgren, 2015). The roundwood trade in the Nordic forest sector is significantly dependent on foreign markets, with commercialization rates of harvested timber ranging from 57% to 89% in Finland, 59% to 81% in Sweden, 61% to 76% in Norway, and 59% to 106% in Denmark (Hu et al., 2024).

Environmental pollution, particularly air pollution from industrial activities and acid rain, presents another major threat to Nordic forests. Approximately 82% of the total forest area in the Nordic region (480,000 km²) is at risk from critical levels of acid deposition (Sverdrup, 1992). The negative effects of acid rain on soil chemistry are particularly pronounced in southeast Sweden and Norway. Despite sustainable forestry policies in Norway and Sweden, industrial pollution continues to threaten forest health (Girdzišius et al., 2021).

This study integrates the EKC and LCC frameworks to analyze the long-run effects of economic growth, carbon intensity, urbanization, and agricultural expansion on forest load carrying capacity in the Nordic countries. Using panel ARDL methods, it

assesses the short- and long-run dynamics of these relationships and develops policy recommendations for sustainable forest management. Although FLCC is often tested across countries with varying income levels, this study focuses on high-income Nordic countries, where sustainable forestry policies are prominent but still face challenges due to economic and industrial pressures. Despite their high-income status, these countries exhibit significant variation in forestry management, industrial dependence, and ecological footprint, making them suitable for testing FLCC within a high-income framework.

This study contributes to the environmental economics literature by being among the first to empirically test both the EKC and LCC hypotheses using FLCC as an ecological sustainability indicator in high-income Nordic countries. While previous studies have largely focused on low- and middle-income countries, our analysis provides new insights into how advanced economies with robust environmental frameworks still face challenges due to agricultural expansion, carbon intensity, and urbanization. Methodologically, the use of the Panel ARDL and PMG estimator allows us to disentangle short-run fluctuations from long-run equilibrium dynamics. The study also offers practical policy implications by highlighting how economic development can be reconciled with forest conservation through tailored sustainability strategies. The novelty of this study lies in its integrated application of the EKC and LCC frameworks using the FLCC indicator in high-income Nordic countries, a context that remains largely underexplored in the existing literature. By combining ecological sustainability theory with dynamic panel estimation techniques, this study bridges a methodological and empirical gap.

Theoretical Framework

The relationship between economic development and environmental change has been one of the focal points of academic studies for many years. In this context, different approaches have been developed to understand the dynamic relationship between environmental pollution and economic growth. First, Kuznets (1955) argued that

economic growth increases income inequality in the initial stages, but after a certain income level, this inequality decreases, suggesting an inverted-U-shaped relationship. Grossman & Krueger (1995) examined a similar relationship in terms of environmental indicators and found that economic growth increases environmental pollution in the initial stages, but environmental quality starts to improve after a certain income level. Panayotou (1993) reinforced this relationship in the literature by naming it the EKC.

The EKC hypothesis explains the impact of economic growth on environmental degradation through an inverted-U shaped relationship. As can be seen in Figure 1, the EKC hypothesis considers the relationship between income growth and environmental pollution in three main stages.

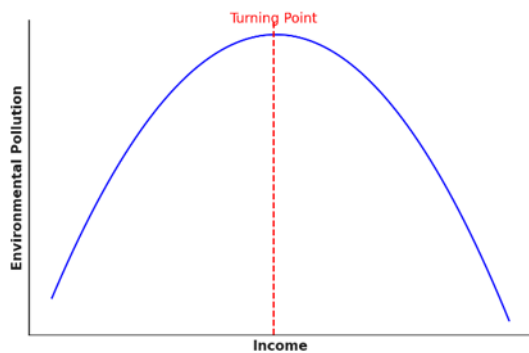


Figure 1. Environmental Kuznets Curve

According to the hypothesis, in the early stages of economic growth, accelerated industrialization, increased energy demand and excessive consumption of natural resources trigger environmental degradation (Gawande et al., 2001). In this process, economic activities are largely based on fossil fuels, environmental costs are ignored and low-efficiency technologies are used in production processes.

After growth reaches a certain threshold, increased environmental awareness, stronger public pressure and tighter environmental policies lead to a slowdown in environmental degradation (Kaika & Zervas, 2013). At this stage, the adoption of sustainable development policies, innovative environmental regulations and green economy approaches stand out as critical factors that improve environmental

performance. In particular, carbon taxes, sustainable production incentives and renewable energy investments reduce the pressure on the environment.

In the last stage, environmental degradation is significantly reduced with the spread of renewable energy technologies, the adoption of environmentally friendly production models and the strengthening of sustainable growth strategies (Aydın & Değirmenci, 2024). This stage represents a period in which the relationship between economic growth and environmental sustainability evolves from conflict to cooperation. With environmental protection policies becoming an integral part of economic growth, long-term ecological balance is ensured and economic growth is positioned as a factor supporting environmental quality.

Many studies in the literature have shown that the EKC hypothesis is valid in different country groups and environmental indicators. Seppälä et al. (2001) argue that economic growth in industrialized countries can reduce environmental pressure, while Apergis & Ozturk (2015) confirm the inverted-U relationship in their panel data analysis for Asian countries. Similarly, Al-Mulali et al. (2016) showed that economic growth in Kenya supports environmental sustainability after a certain level. In the Turkish context, Lebe (2016) argues that energy consumption and economic growth initially increase CO₂ emissions, but after a certain level, environmental pressure decreases. More recently, Fukuda (2024), in his analysis including Türkiye, India and Pakistan, showed that the EKC hypothesis holds after a certain turning point.

However, some studies have shown that the EKC hypothesis is not valid. Von Hauff & Mistri (2015) did not confirm the inverted-U relationship in their study on the impact of economic growth on water resources in India. In Türkiye, Ozcan et al. (2018), in their analysis covering the period 1961-2013, find that the EKC hypothesis is not valid for Türkiye. Similarly, Katircioğlu & Katircioğlu (2018) evaluated the EKC hypothesis with urbanization and energy consumption and found that there is no traditional inverted-U relationship in Türkiye. Beşe & Kalaycı (2021), using ARDL and Granger causality

tests in Denmark, the United Kingdom and Spain, find no evidence to support the EKC hypothesis.

Some other studies have shown that the validity of the EKC hypothesis varies depending on country groups, environmental indicators and methods used. Stern (1998) stated that the EKC hypothesis is more evident in indicators such as CO₂ emissions, but has different results in areas such as water pollution and energy consumption. Sarkodie & Strezov (2019) emphasized that the EKC hypothesis is generally valid in low- and middle-income countries, but the turning point appears later in high-income countries. In a large-scale study covering 44 countries, Maneejuk et al. (2020) found that the EKC hypothesis is valid only in the European Union, OECD and G7 countries. In a more recent study, Ojaghlou et al. (2023) identified an N-shaped EKC curve in Türkiye, showing that economic growth initially increases environmental degradation but decreases under certain conditions.

All these studies show that the EKC hypothesis is not generally valid and may yield different results depending on environmental indicators, methodologies and the economic structure of countries.

The EKC hypothesis has been criticized for assessing environmental sustainability from a single indicator (mostly air pollution). For example, the EKC hypothesis does not fully reflect long-term environmental impacts such as deforestation, biodiversity loss and depletion of water resources (Wiedmann & Barrett, 2010). To overcome the unidirectional perspective of the EKC hypothesis, new approaches have been developed that address both the supply and demand sides of environmental sustainability. In this direction, Siche et al. (2010) proposed the Load Capacity Factor (LCF) indicator. LCF is one of the main indicators that determine the sustainability level of an ecosystem. This factor is calculated as the ratio of the existing Biocapacity (BC) to the Ecological Footprint (EF) resulting from human activities.

This indicator presents different sustainability scenarios by assessing the balance of environmental supply and demand:

- $LCF > 1$: The biocapacity of the region is able to meet ecological demand (sustainable).
- $LCF < 1$: Ecological demand exceeds biocapacity (sustainability risk).
- $LCF = 1$: The environmental carrying capacity limit has been reached (critical threshold).

The main difference of this approach from the EKC is that it examines not only the impact of economic growth on environmental degradation, but also the response of ecosystems to growth (Pata & Işık, 2021).

In this framework, the LCC Hypothesis was developed. The LCC analyzes the impact of income growth on environmental sustainability in a bidirectional way, addressing the carrying capacity of ecosystems and the pressures arising from human activities with an integrated approach (Pata & Tanrıöver, 2023).

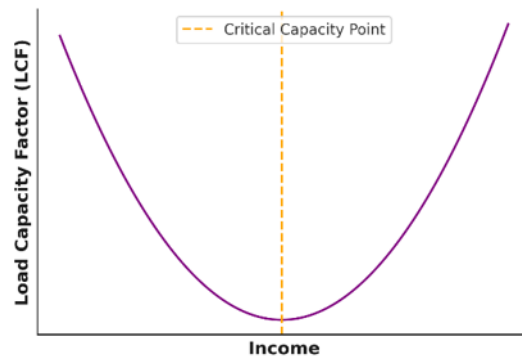


Figure 2. Load Capacity Curve

The LCC hypothesis argues for a U-shaped relationship between income and LCF, as can be seen in Figure 2. In the first stage, consumption of environmental resources increases with economic growth and pressure on natural ecosystems increases. After a certain level of income, environmental management policies, green investments and sustainable development practices come into play, increasing the regenerative capacity of ecosystems. At the end of this process, a stage is reached where economic growth can support environmental sustainability (Pata & Kartal, 2023).

Some studies in the literature have supported the LCC hypothesis by suggesting

that economic growth can increase environmental sustainability when it reaches a certain threshold (Yang et al., 2023; Daştan, 2024; Hossain et al., 2024; Javed et al., 2024; Shahbaz et al., 2024). However, some studies show that the LCC hypothesis is not always valid or has limited validity under certain conditions. Pata & Balsalobre-Lorente (2022) show that tourism, energy consumption and economic growth reduce the LCF in the long run in Türkiye and the LCC hypothesis is not valid. Pata & Tanrıöver (2023), in their study on the world's 10 most popular tourism destinations, showed that financial development decreases environmental quality, but tourism does not support the LCC hypothesis by increasing environmental quality. Aydin & Degirmenci (2024) examined the impact of clean energy consumption, green innovation and technological diffusion on environmental sustainability in European Union countries and found that the LCC hypothesis is not generally valid but supported in countries such as Denmark, France, Portugal and Spain.

Some studies have shown that the validity of the LCC hypothesis may vary by country, sector and environmental indicators. In a panel data analysis on E-7 countries, Feng et al. (2024) found a U-shaped relationship between economic growth and the LCF. This finding suggests that economic growth negatively affects environmental quality in the first stage, but supports environmental sustainability after a certain threshold level. Bekun et al. (2024), in their study for MINT countries, found that the LCC hypothesis is not generally valid, but renewable energy consumption increases environmental sustainability.

These studies show that the LCC hypothesis may be valid under certain conditions but may not be sufficient to explain environmental sustainability on its own. It is emphasized that the LCC hypothesis may differ in terms of different country groups, economic structures and environmental indicators and sustainable development policies should be shaped within this framework.

Material and Methods

Data

The data set used in the study covers the period between 2010-2021 and consists of annual observations from four Nordic countries. The dependent variable, Forest LCC, was calculated using Global Footprint Network data and obtained by dividing the biocapacity per capita by the footprint value. Gross domestic product per capita (GDP per capita), one of the independent variables, was obtained from the World Bank and its natural logarithm was taken to test the EKC hypothesis. Logarithm transformation is preferred to reduce the scale effects of the variable, to make the data more suitable for normal distribution and to examine the effect of economic growth on FLCC in a non-linear manner.

Among the independent variables, carbon intensity is defined as the ratio of total carbon emissions to economic output and obtained from the World Bank. This variable is expected to have a negative impact on FLCC, since as carbon intensity increases, environmental pressures also increase and have negative impacts on forest ecosystems. The urbanization rate is calculated as the ratio of urban population to total population and is also obtained using World Bank data. Considering that urbanization is one of the factors leading to deforestation, this variable is also expected to have a negative impact.

Data on agricultural land use is represented by the agricultural land index from the USDA Economic Research Service. This variable is included in the model to measure the impact of agricultural land expansion on forest ecosystems. Since the expansion of agricultural land may lead to a decrease in forest areas, this variable is also expected to have a negative coefficient.

The Figure 3 shows the course of forest biocapacity per capita in the Nordic countries between 2010 and 2021. Finland stands out as the country with the highest per capita biocapacity in the period under review, while Sweden ranks second. Norway's per capita biocapacity level is lower than in Finland and Sweden and shows a slight downward trend over time. Denmark has by far the lowest biocapacity level, which can be explained by its limited forest areas. Overall, biocapacity levels are relatively stable, with no major

fluctuations over time in all countries. However, the slight downward trend observed in Sweden and Norway indicates

that pressure on forest areas has increased over time and sustainable forest management strategies have become more important.

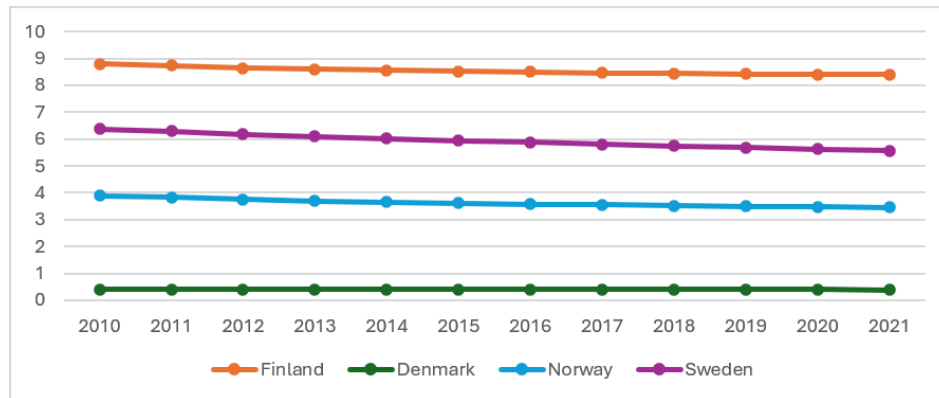


Figure 3. Forest biocapacity (per capita) in Nordic countries, 2010-2021

The figure 4 shows the change in the forest footprint per capita in the Nordic countries between 2010 and 2021. Overall, Sweden has the highest forest footprint, which can be explained by its high forest-based production activities. Although Denmark has the lowest values in terms of biocapacity, it is at a relatively high level in terms of per capita forest footprint, indicating

that the country's consumption of forest products has reached a level that exceeds its local biocapacity. Finland has the highest biocapacity, but a relatively low forest footprint per capita. Norway's forest footprint has fluctuated over time, with a particularly marked increase in 2018, but then declined back to a relatively stable level.

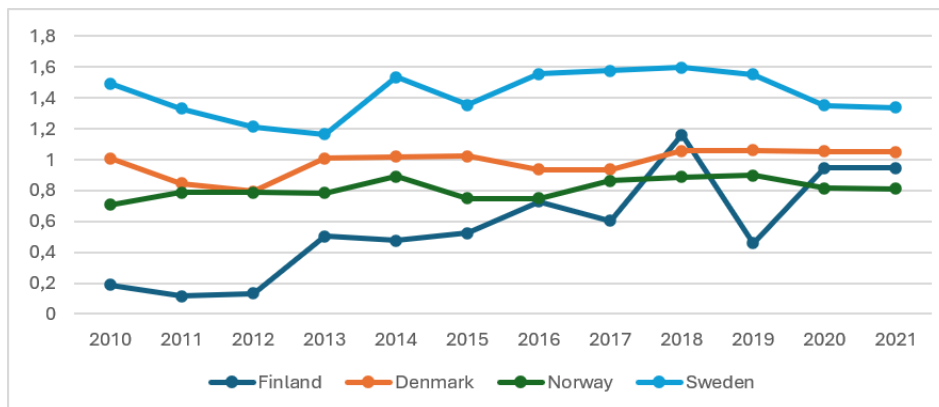


Figure 4. Forest footprint (per capita) in Nordic Countries, 2010-2021

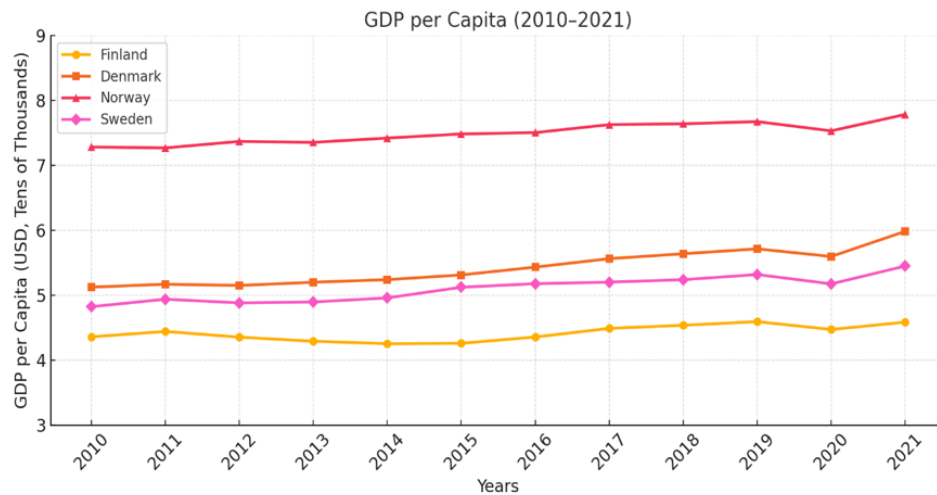


Figure 5. GDP per capita in Nordic countries, 2010-2021

Figure 5 illustrates the historical trend of GDP per capita for four Nordic countries — Finland, Denmark, Norway, and Sweden — during the 2010–2021 period. The data reveal a consistent upward trajectory in income levels, with Norway maintaining the highest per capita GDP throughout the period, followed by Denmark. Although a modest decline is observed in 2020 due to the COVID-19 pandemic, the overall trend confirms the sustained high-income status of these countries. By presenting these income dynamics, the figure reinforces the empirical basis for including GDP per capita as a central variable in testing both the EKC hypothesis and in modeling the effects of economic growth on FLC in the Nordic context.

When the descriptive statistics of the variables used in the model are analyzed (Table 1), it is seen that FLCC varies

significantly across countries and over time. This shows that the sustainability of forest ecosystems is affected by different dynamics and that structural differences between countries are significant. The logarithm of GDP per capita, which represents economic size, has a relatively balanced distribution across countries, while the low levels of the carbon intensity variable suggest that Scandinavian countries have a relatively low emission production structure. The urbanization rate is generally high, indicating that urbanization is at an advanced stage in these countries and serves as an important indicator for understanding the pressure exerted by expanding urban areas on natural areas. Agricultural land shows small changes over time, which can be attributed to the stability of agricultural policies and land use transformation processes.

Table 1. Descriptive Statistics

	FLCC	ln(GDP)	Land	Carbon	Urban
Mean	8.664	10.914	100.731	0.132	85.142
Max.	74.983	11.262	107.233	0.282	88.240
Min.	0.327	10.657	98.543	0.071	79.102
Std. Error	14.992	0.199	1.751	0.051	2.607
Obs.	48	48	48	48	48

Panel ARDL method is used in the study and PMG estimator is preferred as the estimator. This method is an appropriate approach for analyzing long-run equilibrium relationships and dynamic interactions between variables. The coefficients and significance levels obtained as a result of the

analysis will provide important findings in understanding the impact of economic growth, carbon emissions, urbanization and agricultural areas on FLCC in the Nordic countries.

Methodology

This study utilizes panel data econometric techniques to investigate the FLCC components in the Nordic region, Sweden, Norway, Finland and Denmark between 2010 and 2021. Given the time series and horizontal cross-sectional nature of the data set, panel unit root tests are first conducted to examine the stationarity of the variables, followed by panel cointegration tests to assess the existence of a long-run equilibrium relationship. The Pooled Mean Group (PMG) model is estimated to explain the long-short run relationships between the variables and compared with the Mean Group (MG) and Dynamic Fixed Effects (DFE) models and Hausman test is used to determine the most appropriate estimator.

To ensure the validity of the econometric analysis, we first examined the stationarity properties of the variables using the Im, Pesaran and Shin (IPS) test (Im et al., 2003) and the Breitung test (Breitung, 2000). The IPS test allows for heterogeneous autoregressive parameters across cross-sections and is based on the following equation:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \sum_{j=1}^p \delta_{ij} \Delta Y_{i,t-j} + \epsilon_{it} \quad (1)$$

In Equation 1, Y_{it} is the dependent variable for region i at time t , α_i is the individual fixed effect, β_i is the coefficient measuring stationarity and ϵ_{it} is the error term. The null hypothesis assumes the presence of a unit root, implying non-stationarity, while the alternative hypothesis implies stationarity at least for some cross-sections. Similarly, the Breitung test, which imposes common autoregressive parameters across panels, is also applied to confirm stationarity. Once stationarity is established, we proceed to panel cointegration analysis.

Pedroni (1999; 2001) and Kao (1999) cointegration tests are applied to determine whether there is a long-run relationship between the factors affecting FLCC. The Pedroni test extends the Engle-Granger methodology to panel data by estimating the following regression:

$$Y_{it} = \alpha_i + \delta_i t + \beta X_{it} + \epsilon_{it} \quad (2)$$

where Y_{it} is the dependent variable (FLCC) and X_{it} is the independent variables (ln(GDP) and its square, Land, Urban, Carbon).

Moreover, α_i accounts for individual fixed effects and δ_i for deterministic trends. The Pedroni test tests for cointegration by checking whether the error term is stationary. According to the results of this test, which is analyzed with various statistics, there is a long-run relationship between the variables.

If cointegration is confirmed, the Pooled Mean Group (PMG) estimator is applied to distinguish between short-run and long-run relationships. The PMG model developed by Pesaran et al. (1999) is particularly suitable for panel data sets with large time dimension.

Homogeneity while allowing for short-run heterogeneity across cross-sections. The general form of the PMG model is as follows:

$$\Delta Y_{it} = \varphi_i (Y_{i,t-1} - \theta_i X_{it}) + \sum_{j=1}^{p-1} \gamma_{ij} \Delta Y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij} \Delta X_{i,t-j} + \epsilon_{it} \quad (3)$$

In equation 3, φ_i is the error correction term, θ_i is the long-run coefficient, while δ_{ij} and γ_{ij} are the short-run dynamics. For robustness, the PMG model with the Mean Group (MG) estimator (Pesaran & Smith, 1995) and the Dynamic Fixed Effects (DFE) model are compared. Unlike the PMG, the MG estimator allows for heterogeneity in both long-run and short-run coefficients by estimating individual country regressions and averaging the coefficients across cross-sections:

$$Y_{it} = \alpha_i + \beta_i X_{it} + \epsilon_{it} \quad (4)$$

In contrast, the DFE model imposes homogeneity on both short-run and long-run coefficients and estimates a single equation for all horizontal cross-sections. The choice between these models is guided by the Hausman test, which assesses whether the homogeneity restriction in PMG holds. To identify the most appropriate model, we apply the Hausman (1978) test, which compares the efficiency and consistency of the PMG and MG estimators. The test statistic is calculated as follows:

$$H = (\hat{\beta}_{MG} - \hat{\beta}_{PMG})' V^{-1} (\hat{\beta}_{MG} - \hat{\beta}_{PMG}) \quad (5)$$

where $\hat{\beta}_{MG}$ and $\hat{\beta}_{PMG}$ are the estimated coefficients from the MG and PMG models and V represents the variance-covariance matrix. The null hypothesis states that PMG is efficient, while the alternative hypothesis states that MG is preferable due to long-run heterogeneity. A statistically significant test result favors MG over PMG, while an insignificant result supports the use of PMG as the preferred model.

To determine the income threshold at which the EKC and LCC relationships reverse direction, the turning point of the quadratic functional form was calculated. Specifically, the estimated coefficients of $\ln(\text{GDP})$ and its squared term from the PMG model were used to compute the turning point based on the formula:

$$\text{Turning point} = \exp \left(-\frac{\beta_{\ln \text{GDP}}}{2\beta_{\ln \text{GDP}^2}} \right) \quad (6)$$

This formula provides the level of per capita income at which the marginal effect of economic growth on forest load carrying capacity (FLCC) shifts from negative to positive, consistent with the theoretical underpinnings of the EKC and LCC hypotheses. The turning point serves as a critical benchmark in identifying the stage at which environmental improvements are expected to emerge with further economic growth. The interpretation and methodological basis of such turning point estimations are supported by Stern (2004), who highlights the importance of identifying income thresholds in environmental-economic models to better inform policy design in both developed and developing economies.

Using panel unit root tests, cointegration analysis and dynamic panel estimation, this study provides robust econometric modeling to investigate the long- and short-run dynamics between public education spending

and income inequality. Besides robustness checks using MG and DFE models, the PMG approach provides a comprehensive understanding of both heterogeneous and homogeneous effects across countries in the Nordic region. The Hausman test also validates the appropriate estimator and ensures the reliability of our findings in informing education policies aimed at reducing income inequality.

Results

In this study, panel data analysis techniques are applied to analyze the determinants of FLCC in Scandinavian countries. Unit root tests were performed to examine the stationarity properties of the variables over time, and cointegration tests were applied to determine the long-run equilibrium relationships. Long- and short-run relationships were estimated with the panel ARDL method, and the most appropriate model was determined by comparing PMG, MG and DFE estimators. The findings reveal the effects of economic growth, carbon intensity, urbanization and agricultural activities on FLCC and provide important results in terms of environmental sustainability.

According to the results of the unit root tests in Table 2, the stationarity properties of the variables used in the model are analyzed. Both IPS and Breitung tests show that the variables are non-stationary at their level values but become stationary when first differences are taken. This implies that the series have $I(1)$ process, that is, they have unit root but become stationary when first differences are taken.

These results indicate that cointegration tests that allow the analysis of long-run relationships between variables should be applied. Unit root tests confirm that panel ARDL and other long-run models can be used when the series are difference stationary.

Table 2. Panel unit root tests

Variables	IPS		Breitung	
	I(0)	I(1)	I(0)	I(1)
FFLC	-1.055 (0.146)	-2.987 (0.001)	-2.426 (0.007)	-2.852 (0.001)
ln(GDP)	0.385 (0.649)	-4.006 (0.000)	-0.092 (0.464)	-2.637 (0.003)
LAND	0.109 (0.544)	-2.958 (0.002)	0.822 (0.794)	-2.741 (0.003)
CARBON	0.917 (0.821)	-4.434 (0.000)	1.019 (0.846)	-5.133 (0.000)
URBAN	0.975 (0.835)	-5.108 (0.000)	1.049 (0.682)	-3.238 (0.001)

According to the results of panel cointegration tests, Pedroni and Kao tests support the existence of a long-run equilibrium relationship between the variables used in the model. The fact that all test statistics are significant indicates that there is cointegration between the variables, that is, they move together in the long run.

Table 3. Panel cointegration test

Pedroni Test*		
	statistic	Prob.
Panel PP	-4.986	0.0001
Panel ADF	-2.996	0.0014
Group PP	-7.563	0.0001
Group ADF	-2.431	0.0075
KaoTest*		
	t-stat	Prob.
ADF	-2.795	0.0026

*The delay length was chosen according to the Schwarz information criterion. The Bartlett kernel method was used and the bandwidth width was determined by the Newey-West method.

This finding reveals that factors such as economic growth, carbon intensity, urbanization and expansion of agricultural areas have long-run effects on FLCC. As a result of the unit root tests, the variables were found to be I(1), so the finding of cointegration relationship suggests that models such as panel ARDL are applicable for estimating long-run equations. The results emphasize that pressures on forest ecosystems create permanent effects over time and that sustainability policies should be addressed with a long-term perspective.

Table 4. Cross section dependency

Tests	Statistics	Probability
Breusch-Pagan Chi-square	10.174	0.1175
Pearson LM Normal	0.051	0.9599
Pearson CD Normal	-0.521	0.6027
Friedman Chi-square	8.950	0.6265

According to the results of the cross-sectional dependence tests in Table 4, Breusch-Pagan, Pearson LM, Pearson CD and Friedman Chi-square tests do not indicate a significant cross-sectional dependence. The probability values of all tests are above the significance threshold of 5% (0.05), indicating that there is no cross-sectional dependence in the model (Friedman, 1937; Breusch & Pagan, 1980; Pesaran, 2004).

This finding suggests that the factors affecting FLCC among Nordic countries may act independently and that the environmental sustainability policies of the countries may differ significantly from each other (Pedroni, 1999; Westerlund, 2007). If cross-sectional dependence were present, the panel data model would require the use of generalized estimators or second generation panel methods (Pesaran, 2007). However, since the test results show that there is no dependence, the estimates made with first generation panel data methods such as PMG can be considered reliable (Pesaran et al., 1999).

In Table 5, according to the Hausman test results, there is no statistically significant difference between the PMG and MG models in the analysis conducted to test whether the long-run coefficients are homogeneous. The non-significant Hausman test statistic

supports the assumption that the long-run coefficients are homogeneous and indicates that the PMG model is more appropriate (Pesaran et al., 1999). This result suggests that the long-run factors affecting forest freight carrying capacity show similar trends across Nordic countries. If the Hausman test had been significant, it would have been accepted that there are long-run differences between countries and the MG model would have been preferred. However, in this study, the PMG model provides an approach that takes into account both panel and country-specific effects by treating long-run coefficients as homogeneous and short-run coefficients as heterogeneous.

When the differences between PMG, MG and DFE estimators are evaluated, it is observed that the PMG model ensures homogeneity in terms of long-run coefficients while allowing heterogeneity in short-run dynamics. By assuming that both long-run and short-run coefficients can be heterogeneous, the MG model is preferred for situations where structural differences across countries are evident (Pesaran & Smith, 1995). The DFE model, on the other hand, assumes that both short-run and long-run coefficients are homogeneous and ignores differences across countries within the panel. Based on the Hausman test results, the most appropriate model is PMG and the results of this model are discussed in detail.

Table 5. PMG (1,1,0,1,1,1)

	PMG	MG	DFE
	Long-run	Long-run	Long-run
ln(GDP)	-667.931**	-592.965*	-776.894*
sqr(ln(GDP))	30.608**	32.949**	31.563*
LAND	-0.069***	-0.082	-0.112
CARBON	-7.459**	-6.114*	-8.126*
URBAN	-0.581**	-0.024	-0.097
	Short-run	Short-run	Short-run
ECM	-0.829***	-0.935***	-0.739***
D(ln(GDP))	29.474	18.426	19.688
D(LAND)	3.316	3.771	1.580
D(CARBON)	-71.738	-25.663	-27.667
D(URBAN)	24.137	19.854	17.943
C	3073.071***	2743.968*	3484.475*
Hausman Test	-	0.1253	0.1540

Note: *, **, *** denotes 10%, 5%, and 1% significance values, respectively.

According to the estimation results of the PMG model, the logarithm of GDP per capita is negative and significant, while the quadratic term is positive and significant. This supports the EKC hypothesis (Grossman & Krueger, 1995). The results show that economic growth initially has a negative impact on FLCC, but after a certain income level, environmental sustainability increases. The farmland variable, which refers to the expansion of agricultural activities, has a negative and significant effect in the long run. This finding reveals that the expansion of agricultural land puts pressure on forest ecosystems and causes deforestation. This result is consistent with previous studies examining the relationship between agricultural expansion and deforestation (Meyfroidt, 2018). If the

sustainability of agricultural activities is not ensured, it is inevitable that forest load-bearing capacity will decrease. Therefore, agricultural policies should be shaped in line with the principles of environmental sustainability.

The carbon intensity variable is found to be negative and significant in the long run. This finding is consistent with the literature showing the pressure of carbon emissions from industrialization and energy consumption on forest ecosystems (Stern, 1998). Increasing carbon emissions weaken ecosystem services by reducing the load-bearing capacity of forests. Especially when energy consumption based on fossil fuels remains high, carbon sequestration in the atmosphere increases and ecological degradation occurs, accelerating

deforestation. Therefore, adopting low-carbon economic policies, encouraging renewable energy investments and implementing policies to reduce carbon emissions are of great importance for the protection of forest ecosystems.

The urbanization variable is found to be negative and significant in the long run. This finding indicates that urbanization reduces FLCC. However, the fact that this effect is not statistically significant in MG and DFE models reveals that the impact of urbanization on forest ecosystems may differ from country to country. The impact of urbanization on forest assets may vary depending on the extent to which urban planning policies comply with sustainability principles. Unplanned urbanization can lead to the opening of forest areas for development and disruption of ecosystem balance (Seto et. al, 2012). Therefore, it is necessary to formulate urban policies that encourage forest conservation and manage urban expansion within the framework of environmentally friendly approaches.

The coefficient of the error correction mechanism is negative and significant. This result indicates that there is a long-run equilibrium among the variables in the model and that short-term deviations tend to be corrected in the long run. The magnitude of the ECM coefficient indicates how fast the equilibrium between variables is achieved. The magnitude of the error correction coefficient in the study indicates that the speed of return of short-term shocks to long-run equilibrium is high. This finding suggests that policy interventions can have an impact on environmental sustainability and that the measures to be taken will have long-term consequences.

Short-run estimation results show that GDP per capita and agricultural land do not have a significant effect on FLC in the short run. Although the environmental effects of economic growth are not clearly felt in the short run, it is understood that this effect becomes evident in the long run. While carbon intensity shows a negative effect in the short run, its long-run effect is stronger. This result indicates that carbon emissions create cumulative accumulation over time and negatively affect environmental sustainability in the long run. While the

urbanization variable has a positive effect in the short run, it is found to be negative and significant in the long run. This finding indicates that urbanization may have positive effects in the short run through economic development and infrastructure investments, but in the long run it becomes one of the factors that reduce forest load carrying capacity.

When the results are evaluated in general, economic growth, agricultural land expansion, carbon intensity and urbanization stand out as important variables determining forest load carrying capacity in Scandinavian countries. The validity of the EKC hypothesis suggests that economic growth can increase environmental sustainability after a certain stage. However, in order to achieve this transformation, policies to reduce carbon emissions should be implemented, the environmental impacts of agricultural expansion should be controlled and urbanization should be managed sustainably. The robustness of the long-run error correction mechanism suggests that policy measures can be effectively implemented to maintain the environmental balance. In conclusion, this study reveals that sustainable development policies play a critical role for the conservation of forest ecosystems in the Nordic countries and it is especially important to reduce the negative impacts of carbon emissions and urbanization on the environment.

According to Stern (2004), based on the estimated coefficients of $\ln(\text{GDP})$ and its squared term, the income turning point in the PMG model is calculated as approximately 54,884 USD per capita. This threshold marks the point at which the EKC begins to bend downward, indicating a shift from increasing to decreasing environmental pressure. Simultaneously, it corresponds to the minimum point of the LCC, where forest load carrying capacity starts to recover as economic growth continues. Economically, this implies that once a country surpasses a certain level of per capita income, investments in cleaner technologies, environmental regulations, and sustainable land use practices may become more prevalent, thereby enhancing ecosystem resilience and reversing previous environmental degradation.

Discussion and Conclusion

The study analyzes the economic and environmental factors determining forest LCC in the Nordic countries and examines the long-term effects of economic growth, carbon intensity, urbanization and agricultural activities. In this context, in order to contribute to the literature on environmental sustainability and ecosystem management, the EKC hypothesis and the load carrying capacity hypothesis (LCC) were tested for the Nordic countries. Unlike the EKC analyses in the literature, which generally focus on developing countries, this study for the Nordic countries, which have developed economies, reveals whether similar trends are valid in industrialized countries in terms of environmental sustainability. In this respect, the study contributes to the existing literature by elaborating the relationship between economic growth and environmental sustainability in a specific regional context.

The panel data analysis applied in the study provides a comprehensive method to understand how economic and environmental dynamics change over time and how they are interrelated in the Nordic countries. Both short-run and long-run relationships are analyzed with the panel ARDL method, and according to the Hausman test results, the PMG model is found to be the most appropriate estimator. This suggests that in the long run, the factors affecting forest freight carrying capacity across countries show similar trends. However, since cross-sectional dependence tests were not significant, it was concluded that countries can act independently of each other in the short run. This calls for different approaches in terms of policy recommendations. Although similar long-run trends are observed across the Nordic countries, it should be taken into account that each country's environmental sustainability policies and economic structures have different effects in the short run.

The findings of the study suggest that the EKC hypothesis is valid for the Nordic countries. This suggests that economic growth increases environmental degradation up to a certain level, but environmental improvements are observed after a certain income level. These results are consistent

with previous studies testing the relationship between economic growth and environmental sustainability. For example, Grossman & Krueger (1995) examine the relationship between environmental quality and economic growth and find that above a certain income level, environmental degradation decreases. Similarly, Stern (2004) argues that economic growth can provide long-term environmental benefits if it is supported by sustainable environmental policies. However, the validity of this hypothesis depends on the effectiveness of environmental policies. While Scandinavian countries can accelerate the decline of the EKC curve with their high level of environmental awareness and sustainable development policies, this transformation process may take longer in developing countries.

The empirical estimation of the EKC and LCC models reveals a common turning point at approximately 54,884 USD per capita, based on the coefficients of $\ln(\text{GDP})$ and its squared term in the PMG model. This income level signifies a critical threshold beyond which the negative environmental impacts of economic growth begin to diminish, in line with the EKC hypothesis. Simultaneously, it marks the point at which forest load carrying capacity (FLCC) starts to improve, supporting the U-shaped relationship suggested by the LCC hypothesis. From an economic standpoint, this turning point reflects the stage at which countries tend to adopt more stringent environmental regulations, invest in green technologies, and implement sustainable land-use policies. These structural transformations help mitigate ecological degradation and enhance ecosystem resilience. In the context of Nordic countries, which already operate at relatively high income levels, reaching and maintaining this threshold is crucial for aligning economic development with long-term environmental sustainability.

The carbon intensity variable has a negative and significant effect on forest load carrying capacity in the long run. This result indicates that carbon emissions put significant pressure on forest ecosystems and this pressure reduces forest load carrying capacity over time. Stern (2004), while emphasizing the effects of increasing carbon

emissions on global climate change, states that carbon emissions cannot be reduced without sustainable environmental policies in countries with high energy consumption. The findings of this study also support this view. Accelerating the transition to a low carbon economy in the Nordic countries is a critical step to minimize the impact of carbon emissions on environmental degradation. Especially in fossil fuel-based economies such as Norway, the transition to green energy needs to be realized faster. Norway is a high-risk country in terms of carbon emissions due to its economic structure based on oil and natural gas revenues. Therefore, stricter implementation of policies to reduce carbon emissions will play an important role in reducing pressure on forest ecosystems.

Agricultural expansion has been identified as another factor that negatively affects forest load-bearing capacity in Scandinavian countries. Meyfroidt et al. (2018) state that there is a direct relationship between the expansion of agricultural land and deforestation and that ecosystems can be damaged if agricultural land is not managed sustainably. The findings of the study are in line with this view and show that there is a long-term relationship between agricultural expansion and reduced forest load-bearing capacity in the Nordic countries. In the case of Sweden, agricultural expansion increases the pressure on forest ecosystems and sustainable agricultural policies need to be more comprehensive. Although Sweden is a country that has been able to preserve its forest cover to a large extent, it is observed that the ecological balance has deteriorated in some regions due to agricultural expansion. The implementation of environmentally friendly policies in agricultural production processes will be an approach that will support ecological sustainability.

It has been determined that urbanization reduces FLCC in the long term. This result is consistent with the literature examining the negative effects of urbanization on environmental sustainability (Seto et al., 2012). Although Denmark is a prominent country among the Nordic countries in terms of sustainable urbanization policies, it has been determined that urban growth can negatively affect forest assets. Therefore, green infrastructure should be strengthened

and policies to protect forest ecosystems should be implemented more strongly in urban planning.

At the regional level, it is crucial to develop common policies to reduce carbon emissions across the Nordic countries. Promoting carbon neutral forestry practices, protecting biodiversity and increasing sustainable urbanization projects are among the most important components of this process. Finland should further develop sustainable forest management practices, taking into account the economic importance of the forestry sector. Norway should accelerate its green energy transition by reducing its dependence on fossil fuels. Denmark should increase the number of ecological corridors by implementing sustainable urbanization projects on a larger scale. Sweden should implement policies to reduce the environmental impact of agricultural activities. Within a common regional cooperation framework, carbon trading mechanisms should be used effectively and financial incentives to prevent deforestation should be increased.

Theoretically, this study extends the application of both the EKC and LCC frameworks by providing empirical support for their validity in high-income countries, specifically within the context of forest load carrying capacity. While most previous studies have focused on CO₂ emissions or composite ecological indicators, the use of FLCC introduces a more ecosystem-specific sustainability dimension. This approach deepens our understanding of how economic dynamics interact with biocapacity and environmental thresholds in developed economies.

Practically, the findings inform policy directions in forestry management, land-use regulation, and urban planning. The negative long-run effects of agricultural expansion and urbanization on FLCC emphasize the urgent need for integrative spatial planning and sustainable agricultural policies in the Nordic region. Moreover, the impact of carbon intensity highlights the importance of accelerating green energy transitions to mitigate pressure on forest ecosystems. These results can help guide national and regional authorities in designing targeted interventions to ensure environmental

sustainability in line with long-term economic growth.

The study has some limitations. The fact that the data set is limited to the 2010-2021 period shows that different results can be obtained with longer-term analysis. Future studies should address the impacts of climate change, industrial policies and environmental regulations on forest ecosystems in a broader perspective. Policy effectiveness should be evaluated through country-based case studies and regional sustainability models should continue to be developed.

A broader study encompassing countries from different income levels would provide a more comprehensive assessment of FLCC. However, focusing solely on Nordic countries allows for an in-depth analysis of FLCC dynamics in advanced economies with strong sustainability policies but distinct environmental and economic challenges.

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Author Contributions

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Conflict of Interest

The authors declare that they have no conflict of interest.

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