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Does biomass affect economic growth in Emerging European countries? A note from a dynamic panel model

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Abstract

The impact of biomass on economic growth has recently been debated in empirical literature, with biomass (a component of renewable energy sources) being identified as a key driver of economic growth. The paper empirically explores this link for 11 Emerging EU Countries (EEU_11) and 6 emerging non-EU countries (NEU_6) for two periods: 1998-2019 (unaffected by the pandemic) and 1998-2024 (impacted by the COVID-19 crisis) using dynamic panel models (including Pesaran et al. (1999)'s Pooled Mean Group estimator) and non-linear panel models (such as Gonzales et al. (2017)) for robustness checks. When a linear relationship is found, it appears that biomass has a beneficial effect on economic growth, mainly, in the long run (validating the feedback hypothesis). When analyzing the hypothesis of non-linearities associated to the biomass-growth nexus, the relationship takes the form of an inverted U in the long-run (meaning that biomass has a positive effect on economic growth until a certain threshold is reached, beyond which the association turns negative), whereas this relationship does not hold in the short run. Results also show that biomass energy is a source of non-linearity for the two groups of countries. In terms of policy implications, governments should prioritize efficient investment projects to boost economic growth and expand the renewable energy industries, particularly the modern biomass sectors.

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1. Introduction

The United Nations's seventh Sustainable Development Goal calls for more investment in renewable energy to tackle climate change and its effects, which affect millions of people worldwide. Renewable energy accounted for 17% of total consumption in 2017, yet energy efficiency grew only 1.7%, well below the required 3.0%. Because of the COVID-19 pandemic and the Russian Ukrainian war, fossil resources such as natural gas, petroleum, and coal have become more expensive, thereby demanding greater investment in renewable energy. As emerging markets such as China, India, Brazil, and potentially Africa play a crucial role in global energy consumption, boosting investments in these regions enhances energy security, economic growth, social welfare, and living standards. In this context, modern biomass is viewed as a developing, non-intermittent renewable energy source with significant potential for global expansion. Biomass (biogas, biowaste, wood, and residues), derived from forestry and industrial waste, food and paper waste, animal waste, agricultural residues, and other sources, account for 50-60% of the EU's renewable mix and roughly 90% of rural energy in developing countries (Bildirici 2013). It fertilizes the soil, regenerates underutilized and degraded lands, reduces oil reliance and energy poverty, and enhances biodiversity and water retention as a neutral carbon sink. According to the IEA's sustainable development scenario, bioenergy will account for 15% of total energy production by 2050.

In emerging European countries, biomass is an important source of heating, particularly in rural regions, as opposed to advanced countries (such as Sweden), where biomass (derived from forest wastes and discarded wood) is utilized for urban heating and energy generation. Lithuania and Romania have the most biomass per capita (about 5.9 tons), followed by Hungary and Poland (around 4.9 tons). Among accessing countries to European Union (EU), Ukraine, Moldova, and Belarus, have the highest biomass per capita (between 6.6-7.6 tons).

A couple of recent studies turn on the relationship between biomass and GDP growth nexus (e.g., Bildirici (2014) for transition countries, Ajmi and Inglesi-Lotz (2020), Bilgili and Ozturk (2015a, 2015b) for advanced countries or for African countries, Bildirici (2012) for Latin America countries, Bildirici and Ozaksoy (2013) for both advanced and emerging countries). Their common feature is that they search for *a linear* relationship between biomass and economic growth through the application of dynamic panel models, such as the ARDL approach. In addition, four major hypotheses arise from this body of research. The neutrality hypothesis highlights that biomass energy does not promote economic growth. The central tenet of the second hypothesis, the conservation hypothesis, is that growth is the driving force of biomass energy consumption. In contrast to the growth hypothesis, which points out the importance of biomass energy consumption for economic growth, the feedback hypothesis states that there is a two-way interaction between economic growth and biomass energy use. The source of all these hypotheses can be traced back to the seminal paper by Kraft and Kraft (1978) studying the link between energy use (from non-renewable sources) and GDP growth.

Compared to previous empirical studies, this paper takes a different way, in the sense that it adopts a different line of empirical reasoning. Specifically, the paper aims to further point out the existence of a non-monotonic relationship between biomass and economic growth: biomass accelerates growth to a threshold, but, after that, this positive effect vanishes. One of the potential reasons behind this nonlinearity is climate change and climate variability which may both occur as simultaneous climate shocks (Anderson et al., 2023).

The study examines the short- and long-term impacts of biomass on economic growth using the autoregressive distributed lag (ARDL) specification, and more precisely, the Pooled Mean

Group (PMG) model of Pesaran et al. (1999). By assuming intercept, slope coefficient, and error variance vary between countries, it also addresses panel cross-section unit variability. Even with endogenous and non-stationary regressors, the PMG model appears consistent and efficient (Pesaran et al., 1999) regardless of the lag order chosen. Another contribution to the existing empirical literature is the focus on a more comprehensive panel of developing countries (17 countries) that comprises two main groups: emerging EU countries (E-EU) and other emerging European countries (non-members of the EU - NEU), across two periods: the first from 1998 to 2019, unaffected by the COVID-19 pandemic, and the second, from 1998 to 2024, impacted by the pandemic crisis.

From the literature review, it results that there is a relatively scant investigation on how biomass affects economic growth. Additionally, no research has examined the potential *non-linear* relationship between biomass energy use and economic growth in emerging European countries, and this paper principally aims to fill this gap. Based on the empirical literature that has already been done on the link between biomass and economic growth (for a review, see Ajmi and Inglesi-Lotz, 2020), two basic hypotheses are tested:

H1: The impact of biomass on economic growth could be both beneficial and harmful.

H2: There is a potential non-monotonous relationship between biomass and economic growth.

Except for table 11 of NEU_6, the results reveal a bidirectional causality between biomass and economic growth over the long term for both groups of countries (see tables 10 to 12 of the Appendix). This supports the feedback hypothesis emphasizing the importance of biomass as a renewable energy source and the potential effects of energy conservation measures. A non-linear relationship between biomass and GDP growth is found for both groups of countries in the long-run horizon. In the short-run, for emerging countries outside the EU, the findings support the "growth hypothesis," stating that biomass energy contributes to economic growth. Conversely, in emerging EU countries, the "conservation hypothesis" is validated, suggesting that a rise in GDP correlates with a reduction in biomass energy consumption. All sub-panels, across the two time periods, confirm the long-run causality between biomass energy use and economic growth, thereby supporting the feedback hypothesis (tables 12 to 14).

The remainder of the paper is as follows. The next section describes the methodology, and the data used in the paper. The third section presents and discusses empirical findings. The final section provides conclusions and policy recommendations.

2. Methodology and data

2.1 Basic econometric specification and data

The impact of biomass energy consumption on GDP growth is investigated for 17 emerging European countries over two distinct periods: one from 1998 to 2019, a period unaffected by the pandemic, and another from 1998 to 2024, which was hit by the covid epidemic crisis.

In relation to the control variables, the study used capital formation and trade openness (following partially Ajmi and Inglesi-Lotz (2020) rather than Ozturk and Bilgili's (2015) who employed population and openness or Bilgili and Ozturk (2014) who taken capital and labor).

The empirical model incorporates the biomass variable and is represented by a set of two equations. The initial model reflects a linear linkage between the biomass energy consumption and economic growth as follows: $GDPG_{it}$ = f($biomass_{it}, TO_{it}, FBK_{it}, Inf_{it}$).

Conversely, the second model captures the non-linear relationship between economic growth and the use of biomass energy: $GDPG_{it}$ = f($biomass_{it}, biomass_{it}^2, TO_{it}, FBK_{it}, Inf_{it}$) where the economic growth ($GDPG_{it}$) is the dependent variable for each country *i* and year *t* and is computed using the natural logarithm of GDP per capita.

The log-linear equation representing the two initial models can be expressed as follows:

$$ln\ GDP_{it} - ln\ GDP_{i,t-1} = \alpha_i + \beta_0 ln\ Biomass_{i,t} + \zeta ln\ X_{i,t} + \varepsilon_{i,t} \quad (1)$$

and

$$ln\ GDP_{it} - ln\ GDP_{i,t-1} = \alpha_i + \beta_0 ln\ Biomass_{i,t} + \beta_1 ln\ Biomass_{it}^2 + \zeta ln\ X_{i,t} + \varepsilon_{i,t} \quad (2)$$

In the estimated models, the dependent variable is the economic growth based on the natural logarithm of GDP per capita for country *i* in year *t* ($i.e., GDPG_{it} = ln\ GDP_{it} - ln\ GDP_{i,t-1} = \Delta lnGDP_{it}$). The variable of interest, biomass energy consumption per capita ($biomass_{it}$) is included in the vector of explanatory variables together with control variables like trade openness (TO_{it}), fixed brut capital formation in percentage of GDP (FBK_{it}) and inflation (Inf_{it})). Also, $\varepsilon_{i,t}\ is$ a white noise error with zero mean and α_i is a country specific intercept which differs across countries. The impact of trade openness (computed as the sum of exports and imports in percentage of GDP) and inflation on economic growth can be both positive and negative. Nonetheless, it is expected that domestic investment would have favorable effect on economic growth as more investments means higher productivity and higher economic growth in the future. Except for biomass, which comes from the Global Material Flow Database, all the other variables use data from World Development Indicators.

The data sample is divided into two groups and corresponds to emerging European countries. The first group consists of the eleven emerging EU member states (EEU_11), including Bulgaria, the Czech Republic, Croatia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. The second includes six emerging non-EU states (NEU_6) such as Albania, Bosnia, North Macedonia, Moldova, Turkey, and Ukraine. The sample comprises two yearly periods: 1998-2019 and 1998-2024.

Regarding the variable of interest, biomass, Figures 1 to 4 (see Appendix) depict changes in biomass energy use across two periods: 1998-2019 and 1998-2024, for the two groups of countries under consideration. Lithuania and Romania have approximately 5.9 tons of biomass per person, whereas Hungary and Poland have approximately 4.9 tons. Ukraine and Moldova have the greatest biomass per capita (between 6.6-7.6 tons) among EU accession countries.

2.2 The PMG model

In examining the dynamic relationship between biomass energy use and economic growth, I employ the linear Pooled Mean Group (PMG) estimator for heterogeneous dynamic panels as proposed by Pesaran, Shin and Smith (1999). This can be expressed for the periods t = 1, 2,..., T and the countries i = 1, 2,…,N. The following equation illustrates the PMG model which defines the linear relationship between biomass and economic growth:

$$GDPG_{it} = \mu_i + \sum_{j=1}^{p} \lambda_{ij} GDPG_{i,t-j} + \sum_{j=0}^{k} \gamma'_{ij} lnBiomass_{i,t-j} + \sum_{j=0}^{q} \gamma'_{ij} lnX_{i,t-j} + \varepsilon_{it} \quad (3)$$

where the dependent variable is the real GDP per capita growth ($GDPG_{it} = \Delta lnGDP_{it}$) and X_{it} is the vector of our explanatory variables with the dimension k × 1. This vector includes variables such as trade openness (TO_{it}), gross fixed capital formation (Inv_{it}), inflation (Inf_{it}), biomass energy use ($Biomass_{it}$), country fixed effects, μ_i; λ_{ij}'s are the lag coefficients of the dependent variable and γ_{ij}'s are the coefficients of the independent variables. The equation (3) can be re-written in the next form:

$$\Delta lnGDP_{it} = \varphi_i\ [\ln GDP_{i,t-1} - \{\beta_{i,0} + \rho_{i,0}\ ln\ Biomass_{i,t-1} + \xi_{i,1} \ln FBK_{i,t-1} + \\ + \xi_{i,2} \ln TO_{i,t-1} + \xi_{i,3} \ln Inf_{i,t-1}\}] + \sum_{j=1}^{p-1} \Lambda^{*\prime}{}_{ij} \Delta lnGDP_{i,t-j} + \\ + \sum_{j=0}^{k-1} \nu^{*\prime}{}_{ij}\ \Delta lnBiomass_{i,t-j} + \sum_{j=0}^{q-1} y^{*\prime}{}_{ij} \Delta lnX_{i,t-j} + \mu_i + u_{it} \quad (4)$$

where u_{it} are the errors independently distributed for the country i and the time t, with zero mean and the variance $\sigma_i^2 > 0$; $\Lambda^{*\prime}$ is the short-run coefficient of the lagged dependent variable (GDP), $\nu^{*\prime}{}_{ij}$ and $y^{*\prime}{}_{ij}$ are the short-run coefficients for the explanatory variables, $\beta_{i,j}$ and $\rho_{i,j}$ are the long-run coefficients while φ_i corresponds to the speed of adjustment coefficient to the long-run equilibrium. Also,

$\varphi_i = -(1 - \sum_{j=1}^{p} \Lambda_{ij})$; $\theta_i = \frac{\sum_{j=0}^{q} \gamma_{ij}}{1 - \sum_k \Lambda_{ik}}$; $\Lambda'_{ij} = -\sum_{m=j+1}^{p} \Lambda_{i,m}$; j= 1,2,…, p-1; and

$\gamma'_{ij} = -\sum_{m=j+1}^{q} \gamma_{i,m}$ with j = 1, 2,…, q-1.

To determine long-term causality, the PMG model (Eq. 4) uses the speed of adjustment coefficient (the error correction term - φ_i), which, assuming the explanatory variables converge to a long-term equilibrium, must be negative. Short-term causality is identified by testing the significance of the coefficients related to the lagged differences of the economic variables ($\Lambda^{*\prime}{}_{ij}$ and $\nu^{*\prime}{}_{ij}$ and $y^{*\prime}{}_{ij}$ in the Eq. 4). Thus, the pooled mean group estimator provides an optimal balance between consistency and efficiency. The long-term growth trajectory is expected to be shaped by similar processes across countries. The short-term dynamics related to the long-term equilibrium path differ across countries due to idiosyncratic news and fundamental shocks (e.g., Kocenda et al., 2012).

2.3 Pre-tests: cross-section dependence, panel unit root tests and cointegration tests

To address the issue of multicollinearity, Tables 1 and 2 in the appendix provide the correlation matrix of the explanatory variables for both subsamples. The explanatory variables exhibit no correlation, allowing for their safe integration into the model. Tables 3 and 4 of appendix present the main descriptive statistics, for both sub-samples, across the two specified periods: unaffected and affected by the COVID-19 pandemic.

To empirically estimate the PMG model (for more details on this methodology, see Matei, 2017), cross-section dependence, panel unit root tests, and cointegration tests are all prerequisites. Table 5 of appendix shows the findings of Pesaran (2004)'s testing of the no-cross-section dependence null hypothesis; the analysis reveals that the null hypothesis is rejected at both the 1% and 5% significance levels, for all variables included in the model, with the exception of trade openness of emerging non-EU countries. However, due to the Breusch-Pagan statistics that indicate cross-section dependence (67.399 (0.000) for the period 1998-2019 and 85.029 (0.000) for the period 1998-2024), this variable will be retained in the sample.

Tables 6 and 7 display the outcomes of the Pesaran (2007) panel unit test performed on variables in both level and first differences, for the two periods: 1998-2019 and 1998-2024. The dataset comprises both stationary and non-stationary series, specifically, I(0) and I(1). Additionally, almost all variables are stationary after first differences (i.e., I(1)). Domestic investment for the EEU_11 and trade openness for the NEU_6 seem to be I(2). Given that Pesaran et al. (1999)

eliminates the need for unit root and cointegration pretesting, providing consistent and efficient parameter estimates in long-term relationships between stationary and integrated variables, the PMG model can be used with confidence[1].

3. PMG results discussion

Table 8 of the Appendix shows the results of the PMG models for the 1998-2019 period (unaffected by the 2020 pandemic crisis). It includes findings for the benchmark model (linear approach, columns 1 and 3) and the non-linear model (columns 2 and 4), applied to two distinct groups of countries: the emerging EU_11 (EEU_11) and the emerging non-EU_6 (NEU_6).

This analysis reveals a non-linear relationship between biomass energy consumption and economic growth in the sub-samples of emerging European countries. More precisely, a clear inverted U-shaped relationship exists between biomass and economic growth in both emerging EU countries and non-EU countries, with the latter exhibiting greater biomass coefficients. The high significance and negative sign of the error-correction coefficients, in all the models shown in Table 8, implies that there is strong evidence of error correction mechanism. The difference in the speed of adjustment to the long-term growth equilibrium is significant, as the EEU_11 country group converges faster than NEU_6, according to both linear and non-linear models presented in columns [1] - [4], regardless of cross-sectional dependence.

The half-life, which is expressed in years, is another way to quantify the convergence speed. It reflects how long it takes after a shock before the deviation in output reduces to half of its impact (Damette et al., 2016). As error-correction coefficients increase in size, half-life values also increase from 1.72 to 2.16 years for emerging EU_11 and from 17.42 to 68.97 years for emerging non-EU_6 countries, depending on model settings. The overall tendency thus seems to confirm a faster adjustment of emerging EU_11 economies (EEU_11).

In both linear PMG subsamples, domestic investment and trade openness have a positive and statistically significant impact on long-run economic growth. Long-term inflation reduces GDP growth in all sub-samples, regardless of whether the PMG models are linear or nonlinear. The non-linear model shows that domestic investment drives economic growth only in the EEU_11. In the short-run, domestic investment, trade openness and inflation volatility positively and significantly affects GDP growth, in all PMG models. In the context of NEU_6, domestic investment is the sole driver influencing economic growth, in the short-run horizon.

It can be also observed a bidirectional causality (see table 10 of Appendix) between biomass and economic growth, in the long run, for both groups of countries (as the speed of adjustments are negative and statistically highly significant). This finding validates the feed-back hypothesis stating the importance of the biomass (as a renewable source of energy) as well as the potential impact of energy conservation measures. The estimates also show a short-run causality from biomass to GDP growth in the EEU_11 and from GDP growth to biomass in the NEU_6, suggesting that this renewable source of energy is essential and warrants further development.

The results for the period 1998-2024, encompassing the 2020 pandemic crisis, are displayed in Table 9. Consistent with the previous table, the estimations for the benchmark model (linear

[1] The cointegration among variables was analyzed using the Westerlund (2007) cointegration test and is available upon request from the author.

approach, columns 2 and 5) and the non-linear models (columns 3, 4, 6, and 7) are conducted for the same groups of countries: the EEU_11 (PMG1 to PMG3) and the NEU_6 (PMG4 to PMG6). The linear analysis indicates that biomass energy consumption exerts a positive and statistically significant influence (at the 1% level) on economic growth for EEU_11, while its effect on non-EU_6 countries is positive, but statistically non-significant.

The non-linear analysis includes two models: one ignores the 2020 pandemic crisis (PMG 2 for EEU_11 and PMG5 for NEU_6[2] of table 9), while the other integrates it by incorporating the Oxford Coronavirus Government Response Tracker (OxCGRT) stringency index (PMG 3 for EEU_11 and PMG6 for NEU_6, same table). This measure combines nine response metrics: school and workplace closures, public gathering restrictions, public transport closures, public event cancellations, stay-at-home requirements, internal movement restrictions, public information campaigns, and international travel controls. The daily index is the average score of nine criteria, each ranging from 0 to 100, showing government policy strictness. It does not suggest or imply the appropriateness or effectiveness of a country's response. Also, a higher index score does not indicate a stronger pandemic response, as it solely reflects household perception on government pandemic measures.

Non-linear models (PMG2 and PMG3 for EEU_11 and PMG5 and PMG6 for NEU6) consistently show an inverted U-shaped link between biomass and economic growth in both emerging and non-EU countries. When the stringency metric is included in the models, the biomass estimated coefficients for emerging countries outside the EU are larger than those for emerging EU countries (PMG3 and PMG6). Furthermore, the related error-correction terms (the speed of adjustment coefficients) indicate that there is strong evidence of error correction mechanism towards the long-term growth equilibrium, with the EEU_11 country group exhibiting a faster convergence than NEU_6. The half-life, measured in years, indicates a faster convergence speed for EEU_11 compared to NEU_6, with 4.30 years for emerging EU countries and 20.95 years for emerging non-EU ones. The explanatory variables of EEU_11 suggest that domestic investment and trade openness have a positive and statistically significant impact on economic growth, with significant levels of 1% and 5%, respectively. In contrast, government stringency measures have a negative influence on economic growth, statistically significant at the 1% level. In the context of NEU_6, domestic investment stimulates again economic growth, at the 1% level of significance, whereas trade openness shows a statistically significant negative effect at the same level. Furthermore, government pandemic efforts have a statistically significant detrimental influence on economic growth, at the 10% level.

Before estimating the pooled mean group model by Pesaran et al. (1999), two alternative models, the mean group and dynamic fixed effect models, have been assessed. The most restrictive estimator is the dynamic fixed-effects estimator, which assumes constant parameters across countries except the intercept, which may vary. The pooled mean group estimator requires all countries to have the same long-term coefficient but distinct short-run coefficients, making it more general than the dynamic fixed-effects estimator. Finally, the mean group estimator assumes economies have short-term and long-term different coefficients, increasing its generality and panel heterogeneity (Kocenda et al., 2012). In other words, the mean group estimator considers that various countries with different endowments and potential for power generation technologies, including biomass, may exhibit different long run and short-run relationships, which is a realistic hypothesis. However, the choice amongst the three estimators involves a consistency-efficiency tradeoff that can be quantified solely through the Hausman

[2] The emerging non-EU_6 is abbreviated by NEU_6 and the emerging EU_11 is named EEU_11.

test (see Tables 8 and 9). Findings on this panel suggest that the pooled mean group estimator provides an optimal balance between consistency and efficiency. This may be due to the expectation of a similar convergence process among European countries influencing the long-term growth path, while idiosyncratic news and fundamental shocks may impact short-term dynamics surrounding the equilibrium trajectory.

Table 11 displays the causality results for models excluding government stringency measures. This model indicates long-run bi-causality for EEU_11, supporting the feedback hypothesis, and a short-run causality from economic growth to biomass, aligning with the conservation hypothesis. The short-run conservation hypothesis posits that policymakers can limit energy consumption without adversely affecting future economic growth. In contrast, the long-run outcomes indicate that changes in one variable will influence the other, as described by the feedback hypothesis. The NEU_6 analysis indicates evidence of both long-run and short-run causality from biomass to economic growth (the growth hypothesis), while only short-run causality is noted from economic growth to biomass (the conservation hypothesis). The growth hypothesis states that energy conservation policies that reduce biomass energy consumption will hurt economic growth. However, even if biomass energy use decreases, the economy may increase because it may need less biomass energy-intensive services.

Table 12, incorporating the stringency measure, reveals that, for EEU_11, long-run bi-causality and short-run causality from GDP growth to biomass (the conservation hypothesis) are present. For NEU_6, there is evidence of both long-run and short-run causality from biomass to GDP growth, supporting the growth hypothesis. As policy implications, this finding suggests that energy policies that promote biomass development technologies help the economy expand.

4. Robustness checks – different scenarios

So far, I have demonstrated through the PMG approach that the relationship between economic growth and biomass energy use is non-linear. Now, my objective is to identify the threshold of biomass consumption growth at which the positive correlation with GDP growth diminishes or ceases. The PSTR methodology enables this, as the regression coefficients undergo a gradual/smooth transition over time when shifting from one regime to another.

The model proposed by Gonzales et al. (2017) addresses this line of reasoning while simultaneously offering robustness checks. The equation for estimating the Panel Smooth Transition Regression is as follows:

$$GDPG_{it} = \mu_i + \beta_0 \Delta BIOMG_{i,t-1} + \beta_1 \Delta BIOMG_{it-1} f(BIOMG_{i,t-1}; \gamma, c) + \zeta \Delta X_{i,t} + \varepsilon_{i,t} \quad (5)$$

where $GDPG_{it}$ is the dependent variable (the real economic growth per capita for country *i* at time *t*), μ_i the individual fixed-effects, $\Delta BIOM_{i,t-1}$ is the biomass growth of the country *i,* at time *t*, the $f(BIOMG_{i,t-1}, \gamma, c)$ is the transition function and $\varepsilon_{i,t}$, the error term which is i.i.d $(0, \sigma_\varepsilon^2)$. $X_{i,t}$ corresponds to the vector of our control variables influencing economic growth and includes the trade openness change ($\Delta\, TOG_{it}$), the domestic investment growth ($\Delta\, FBKG_{it}$), inflation ($\Delta\, CPIG_{it}$), and initial real GDP per capita (GDP0i). The transition function is continuous and integrable on the interval [0,1] and depends on three parameters: the transition variable $BIOMG_{i,t-1}$ which is the lagged country's biomass change, γ-the slope of the transition function (or the endogenous threshold) and *c* is the vector of location parameters such as $c = (c_1,\ldots,c_m)'$, with *m* as the vector dimension. Regime 1, which represents the linear state, occurs when the transition function $f(BIOMG_{i,t-1}, \gamma, c)$ becomes zero. Regime 2 refers to the nonlinear state where the transition function $f(BIOMG_{i,t-1}, \gamma, c)$ equals 1.

In table 13 of the appendix, I estimated this model only for EEU_11, as the subpanel is larger. The findings corroborate earlier results, indicating a non-linear relationship between economic growth and biomass, with a threshold for biomass growth equaling 0.605 bp (as c=-0.5025). Below this estimated threshold, biomass positively influences economic growth; conversely, above the threshold, it exerts a negative impact. This inverted U-shaped link (confirming the previous PMG results) suggests that biomass appear as an alternative renewable energy source to fossil fuels until the threshold of 0.61; however, once this threshold is reached, this clean, biodegradable organic matter of biological, plant, or animal origin releases carbon monoxide, carbon dioxide, nitrogen oxides, and other pollutants. If they are not captured and recycled, burning biomass can release more pollutants than fossil fuels, which harms the environmental quality. It can also be observed that the speed of transition is smooth, with $\gamma = 5.0224$. This finding is compelling and reflects a realistic perspective, as improvements in biomass energy sources and development require time to manifest appropriately.

Tests for linearity reject the hypothesis of a homogeneous relationship between economic growth and biomass, as p-values are statistically significant at the 5% level. Additionally, the test for remaining non-linearity reveals one optimal threshold at c = -0.5025, with a smooth transition speed of $\gamma = 5.0224$.

The second PSTR model (see table 13 of the appendix) includes initial GDP per capita computed as the logarithm of GDP per capita values at five-year intervals. It allows considering the convergence process highlighted by Solow (1956) according to which countries having a lower initial capital stock per capita experience faster growth compared to those with a higher capital stock per capita. Findings show again a non-linear relationship between biomass and economic growth; however, this link is non-significant. Again, domestic investment is found to be a key driver for GDP growth in the emerging EU_11 countries.

Table 14 in the Appendix shows the PSTR results for the EEU_11 countries, covering the period from 1998 to 2024. The table presents the benchmark model from Table 13 (the PSTR1) with two enriched models that integrate the pandemic stringency measure and initial GDP (both with and without biomass growth, including one lag). The non-linearity hypothesis is confirmed solely for the PSTR3 model, which excludes biomass growth as an explanatory variable. The optimal threshold in this scenario is c = 0.1408, accompanied by a smooth transition speed of $\gamma = 11.8049$. Within the first regime, under the biomass growth threshold of 1.152 bp, all explanatory variables (domestic investment, inflation and initial GDP) have the expected sign and are statistically significant at 1% level (apart from the pandemic measure, which is not statistically significant but has the predicted sign). PSTR3 demonstrates that biomass has the potential to be a source of non-linearity. This may be explained by the fact that biomass is itself and inherently sensitive to climate change and climate variability (Anderson et al., 2023).

5. Conclusions and policy implications

This study analyzes the relationship between biomass energy consumption and economic growth across two panels, covering two periods: 1998-2019 (unaffected by the pandemic) and 1998-2024 (impacted by the COVID-19 crisis): a panel of 11 Emerging EU countries and a panel of 6 emerging non-EU economies. For this purpose, the paper employs cross-section and panel unit root analyses, panel cointegration, and investigates the long-run and short-run relationships using a Pooled Mean Group estimators (PMG) by Pesaran et al. (1999). Robustness checks are handled with Gonzales et al. (2017)' method.

The findings from this analysis indicate that there exists a non-linear relationship (an inverted U-shaped) between biomass energy consumption and economic growth within the observed panel data, for all emerging European countries. Additionally, the feedback hypothesis in the long-run places emphasis on the potential impact of energy conservation measures, specifically those that aim to minimize biomass energy consumption, on economic growth. However, biomass energy consumption should hold significant importance for the GDP growth process.

The results indicate that the policy measures aimed at encouraging the utilization of biomass energy in the emerging European countries may contribute to the sustainable development objectives, in the long term. This implies that these economies should appropriately prioritize the promotion of biomass energy availability to sustain long-term economic growth and development. For this, it should enhance the energy policies by focusing on the development of biomass energy infrastructure and the promotion of modern biomass supplies. These measures are key for fostering sustainable economic growth and mitigating greenhouse gas emissions, particularly carbon dioxide emissions (within specific biomass thresholds).

The outcomes also indicate that biomass has the potential to be a source of non-linearity, based on Gonzales et al. (2017)' methodology. This could be due to the fact that biomass is naturally sensitive to climate change and climate unpredictability, which can occur simultaneously. In this sense, Anderson et al. (2023) contend that interannual modes of climate variability, including the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the North Atlantic Oscillation (NAO), have influenced the likelihood of simultaneous yield shocks in pairs of breadbaskets by 20–40% for both maize and wheat. NAO significantly and uniformly influenced the frequency of wheat yield shocks, mostly impacting bread baskets in the northern hemisphere. Since the 1930s, agricultural research and development has enabled the food system to adapt to a warming climate, thereby mitigating the concurrent yield shock of wheat and maize. Considering this study's findings and those of the existing empirical literature on the biomass-economic growth nexus, future research path may explore if climate variability in the countries adjacent to the North Atlantic Ocean could serve as a new potential source of non-linearity for the link between biomass and economic growth, particularly within the agricultural sector and how new technologies could apprehend this new source of change. Another point of reasoning is that droughts, heat waves, fires, and biotic attacks induced by climate variability and their unpredictability are damaging forests in various biomes around the world (including the Northern Hemisphere), affecting biomass and necessitating technological adaptation.

6. References

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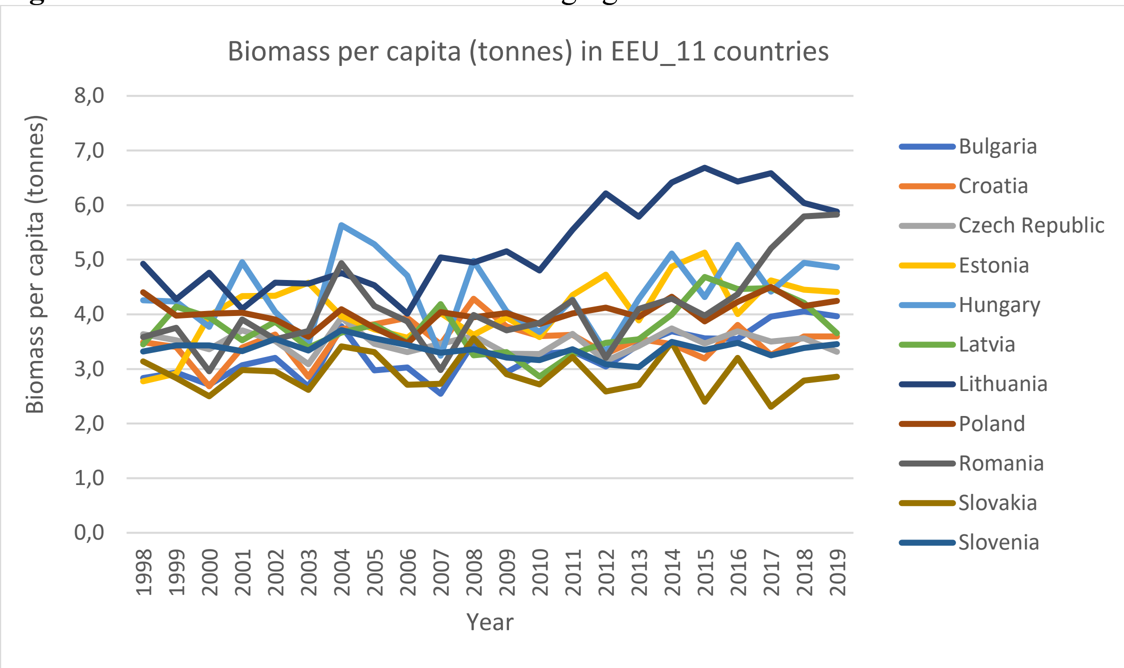
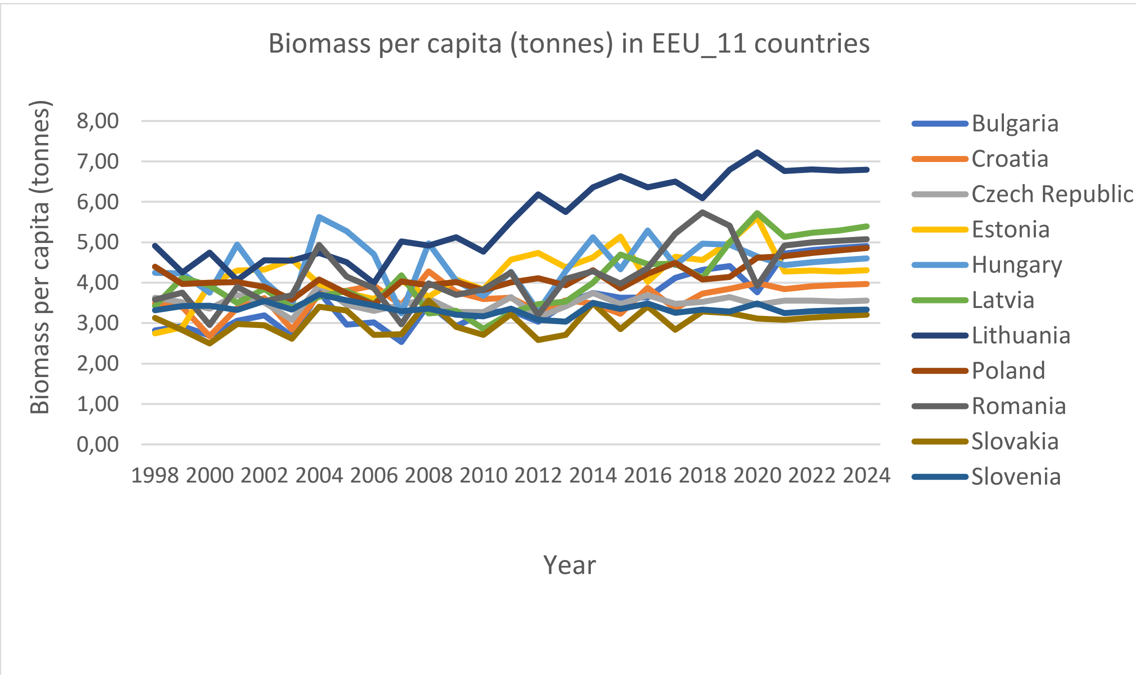
Appendix

Figure 1: The evolution of biomass in emerging EU countries from 1998 to 2019



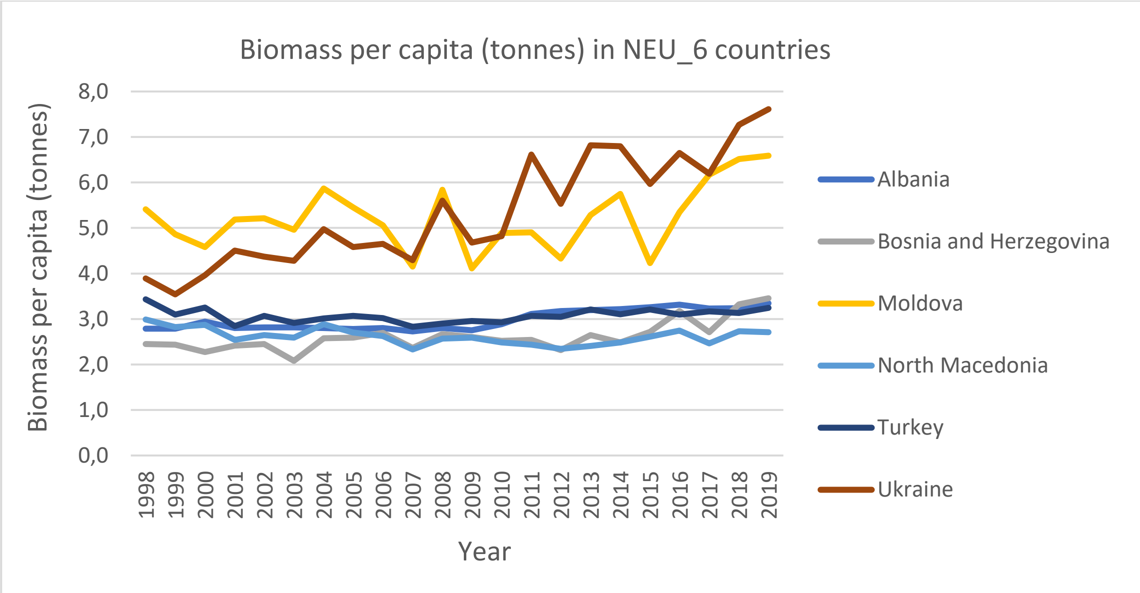
Note: author's computations

Figure 2: The evolution of biomass in emerging EU countries from 1998 to 2024



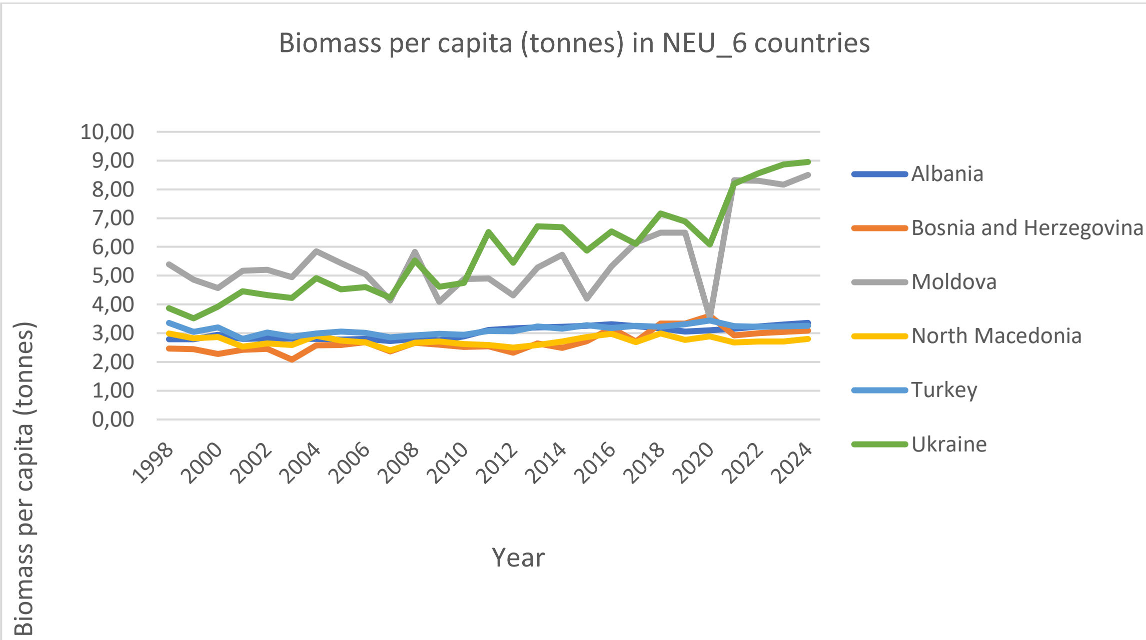
Note: author's computations

Figure 3: The evolution of biomass in emerging non-EU countries from 1998 to 2019



Note: author's computations

Figure 4: The evolution of biomass in emerging non-EU countries from 1998 to 2024



Note: author's computations

Table 1: Matrix correlation between the explanatory variables (ln): **1998-2019**

EU_11	BIOM	INF	FBK	TO
BIOM	1.00			
INF	-0.12	1.00		
FBK	-0.11	0.29	1.00	
TO	0.03	-0.31	0.06	1.00

Non-EU_6	BIOM	FBK	INF	TO
BIOM	1.00			
FBK	-0.42	1.00		
INF	0.38	-0.11	1.00	
TO	0.35	-0.27	-0.19	1.00

Note: i) Author's computations ; ii) EU_11 – the emerging EU countries
iii) Non-EU_6 – the emerging non-EU countries; iv) BIOM – biomass.
INF – inflation, FBK – domestic investment, TO – trade openness.

Table 2: Matrix correlation between the explanatory variables (ln): **1998-2024**

EU_11	BIOM	INF	FBK	TO	STRING
BIOM	1.00				
INF	-0.06	1.00			
FBK	-0.18	0.22	1.00		
TO	0.09	-0.19	0.12	1.00	
STRING	0.19	0.11	-0.08	0.20	1.00

NON - EU_6	BIOM	FBK	TO	INF	STRING
BIOM	1.00				
FBK	-0.48	1.00			
TO	0.26	-0.27	1.00		
INF	0.31	-0.05	-0.15	1.00	
STRING	0.12	-0.10	0.09	0.06	1.00

Note: i) Author's computations; ii) EU_11 – the emerging EU countries
iii) Non-EU_6 – the emerging non-EU countries; iv) BIOM – biomass.
INF – inflation, FBK – domestic investment, TO – trade openness,
STRING – stringency index.

Table 3: Descriptive statistics (variables are in natural logarithms): **1998-2019**

EU_11	BIOM	INF	FBKGDP	TO	GDPPC
Mean	1.32	1.69	3.15	4.69	9.32
Median	1.30	1.79	3.15	4.76	9.37
Maximum	1.90	4.77	3.62	5.25	10.09
Minimum	0.84	-1.22	2.68	3.88	8.17
Std. Dev.	0.20	1.08	0.18	0.31	0.40
Skewness	0.44	-0.42	0.30	-0.40	-0.54
Kurtosis	3.38	3.47	2.67	2.33	2.88
Observations	242	242	242	242	242

Non-EU_6	BIOM	FBK	INF	TO	GDPPC
Mean	1.24	3.16	2.10	4.42	8.14
Median	1.13	3.15	2.35	4.47	8.10
Maximum	2.03	3.64	5.13	4.96	9.39
Minimum	0.73	2.61	-1.24	3.63	7.18
Std. Dev.	0.32	0.21	1.38	0.31	0.54
Skewness	0.79	0.09	-0.40	-0.51	0.42
Kurtosis	2.39	3.01	2.83	2.70	2.66
Observations	132	132	132	132	132

Note: i) Author’s computations; ii) EU_11 – the emerging EU countries; iii) non-EU_6 – the emerging non-EU countries; iv) BIOM – biomass, GDPPC – GDP per capita; INF – inflation, FBK – domestic investment, TO – trade openness.

Table 4: Descriptive statistics (variables are in natural logarithms): **1998-2024**

EU_11	GDPPC	BIOMPC	FBK	TO	INF	STRING
Mean	9.40	1.36	3.16	4.73	1.78	0.43
Median	9.43	1.33	3.16	4.81	1.88	0.00
Maximum	10.17	1.98	3.64	5.32	4.77	4.03
Minimum	8.17	0.91	2.68	3.88	-1.22	0.00
Std. Dev.	0.41	0.21	0.18	0.31	1.08	1.21
Skewness	-0.62	0.53	0.20	-0.51	-0.45	2.48
Kurtosis	2.94	3.17	2.68	2.49	3.35	7.15
Observations	297	297	297	297	297	297

Non-EU_6	GDPPC	BIOMPC	FBK	TO	INF	STRING
Mean	8.23	1.27	3.15	4.43	2.23	0.44
Median	8.21	1.15	3.15	4.47	2.51	0.00
Maximum	9.63	2.19	3.65	5.11	5.13	4.32
Minimum	7.18	0.73	2.47	3.63	-1.24	0.00
Std. Dev.	0.57	0.35	0.22	0.30	1.34	1.24
Skewness	0.38	1.03	-0.21	-0.38	-0.41	2.48
Kurtosis	2.61	3.00	3.45	2.83	3.02	7.19
Observations	162.00	162.00	162.00	162.00	162.00	162.00

Table 5: Cross-section dependence test by CD Pesaran (2004)

Groups of Countries	Emerging EU-11	Emerging non-EU-6
The 1998-2019 period		
Variables (in levels)	Pesaran CD stats	Pesaran CD stats
GDP	33.648*** (0.000)	16.728*** (0.000)
Biomass	9.217*** (0.000)	6.416*** (0.000)
FBK	25.399*** (0.000)	12.351*** (0.000)
TO	28.204*** (0.000)	-0.801 (0.423)
Inflation	24.505*** (0.000)	1.908** (0.056)
The 1998-2024 period		
Groups of Countries	Emerging EU-11	Emerging non-EU-6
Variables (in levels)	Pesaran CD stats	Pesaran CD stats
GDP	37.410*** (0.000)	17.821*** (0.000)
Biomass	14.992*** (0.000)	9.853*** (0.000
FBK	14.548*** (0.000)	1.383 (0.166)
TO	31.629*** (0.000)	-0.619 (0.535)
Inflation	27.888*** (0.000)	4.854*** (0.000)
String	38.520*** (0.000)	20.106*** (0.000)

Note: i) p-values are in parenthesis; ii) ***, ** and * - significance at 1%, 5% and 10% levels, respectively; iii) GDP – GDP per capita. FBK – fixed brut capital formation (domestic investment), TO - trade openness; iv) For Emerging non-UE6 (1998-2024) period, Breusch Pagan test for FBK and TO variables indicate cross-section dependence. Indeed, the Breusch-Pagan LM statistic for FBK is equal to 67.0898 (0.000) and for TO variable is 85.029 (0.000). For the period 1994-2019, the same statistic for TO is 67.399 (0.00).

Table 6: Panel unit root test by Pesaran (2007): **1998-2019**

Emerging EU-11 countries		
Variables/CIPS stats	CIPS stats (var. in levels)	CIPS stats (var. in first differences)
GDP	1.788 (>0.100)	1.218 (>0.100)
Biomass	-5.575 *** (<0.010)	-5.575 *** (<0.010)
FBK	0.0376 (>0.100)	0.0376 (>0.100)
TO	-3.396 *** (<0.010)	-3.396 *** (<0.010)
Inflation	-5.575 *** (<0.010)	-5.575 *** (<0.010)
Emerging non-EU-6 countries		
Variables/CIPS stats	CIPS stats (var. in levels)	CIPS stats (var. in first differences)
GDP	-1.794 (>0.100)	-3.341 *** (<0.010)
Biomass	-7.429 *** (<0.010)	-7.429 *** (<0.010)
FBK	-3.397 *** (<0.010)	-2.768 *** (<0.010)
TO	-0.749 (>0.010)	-1.965 (>0.100)
Inflation	1.007 (>0.100)	-2.448 *** (<0.050)

Note: i) estimates are shown only for models with constant and trend; ii) results with only constant are quite qualitatively similar; iii) p-values are in parenthesis as displayed by Eviews12; iv). ***, ** and * means significance at 1%, 5% and 10% levels, respectively.

Table 7: Panel unit root test by Pesaran (2007): **1998-2024**

Emerging EU-11 countries		
Variables/CIPS stats	CIPS stats (var. in levels)	CIPS stats (var. in first differences)
GDP	-1.155 (>0.100)	-3.541*** (<0.010)
Biomass	-2.689 *** (<0.010)	-2.689 *** (<0.010)
FBK	-3.015** (>0.050)	-4.717*** (<0.010)
TO	-2.758* (<0.100)	-3.365*** (<0.010)
Inflation	-3.741*** (< 0.010)	-3.741*** (< 0.010)
Stringency	114983.103***(< 0.010)	114983.103***(< 0.010)
Emerging non-EU-6 countries		
Variables/CIPS stats	CIPS stats (var. in levels)	CIPS stats (var. in first differences)
GDP	-2.930** (<0.050)	-3.680*** (<0.010)
Biomass	-3.262*** (<0.010)	-3.262*** (<0.010)
FBK	-3.301*** (<0.010)	-3.301*** (<0.010)
TO	-4.586*** (<0.010)	-4.586*** (<0.010)
Inflation	-3.864*** (<0.010)	-3.864*** (<0.010)
Stringency	-.726.198 *** (<0.010)	-.726.198 *** (<0.010)

Note: i) estimates are shown only for models with constant and trend; ii) results with only constant are quite qualitatively similar; iii) p-values are in parenthesis as displayed by Eviews12; iv). ***, ** and * means significance at 1%, 5% and 10% levels, respectively.

Table 8: PMG estimations for EEC countries (linear and non-linear estimates): **1998-2019**

Groups of countries	Emerging EU-11		Emerging Non-EU-6	
Indep. Var. /PMG	PMG1	PMG2	PMG3	PMG4
Long-run coeff.				
Biomass	**0.273*****	**1.198****	**-0.196**	**11.335*****
	(0.023)	(0.498)	(0.440)	(3.405)
Biomass^2	-	**-0.419****	-	**-3.640*****
		(0.181)		(1.234)
Fixed Capital Form.	0.337***	0.455***	0.645***	0.395
	(0.009)	(0.023)	(0.118)	(0.129)
Trade openess	0.028***	-0.081	0.835*	0.819**
	(0.041)	(0.052)	(0.465)	(0.366)
Inflation	-0.002	-0.021***	-1.077*	-0.148*
	(0.003)	(0.006)	(0.045)	(0.070)
Error Correction Term	-0.331***	-0.275***	-0.039***	-0.010***
	(0.071)	(0.049)	(0.019)	(0.022)
Half-life (in years)	1.724	2.155	17.424	68.967
Hausman Test : MG versus PMG	0.67 (0.9545)	0.48 (0.9927)	0.12 (0.9983)	0.00 (1.000)
Hausman Test : MG versus DFE	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)

Note: i) ***, ** and * - significance at 1%, 5% and 10% levels, respectively.

Table 8 (next): PMG estimations for EEC countries (linear and non-linear estimates): **1998-2019**

Groups of countries	Emerging EU-11		Emerging Non-EU-6	
Indep. Var. /PMG	PMG1	PMG2	PMG3	PMG4
Short-run coeff.				
Δ GDPpc $_{t-1}$	0.141***	0.149***	-	-
	(0.051)	(0.041)		
Δ Biomass	**-0.030*****	**-0.120**	0.036	**0.399**
	(0.011)	(0.239)	(0.039)	(0.478)
Δ Biomass²	-	**-0.046**	-	**-0.174**
		(0.096)		(0.220)
Δ Fixed Capital Form.	0.114***	0.119***	0.148***	0.166
	(0.029)	(0.019)	(0.032)	(0.031)
Δ Trade openess	0.105***	0.115***	-0.021	-0.006
	(0.032)	(0.032)	(0.053)	(0.056)
Δ Inflation	0.005**	0.007**	0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.003)
Constant	2.000***	1.452***	0.052***	-0.034
	(0.412)	(0.264)	(0.009)	(0.136)
Trend	0.005***	0.004***	-	-
	(0.001)	(0.0009)		
No. Obs.(N x T)	220	220	126	126
No. Countries	11	11	6	6
ARDL(p,q) with AIC	(2.1,1,1,1)	(2.1,1,1,1)	(1.1,1,1,1)	(1.1,1,1,1,1)
Log-Likehood	673.771	676.246	363.714	375.669

Note: i) ***, ** and * - significance at 1%, 5% and 10% levels, respectively

Table 9: PMG estimations for EEC countries (linear and non-linear estimates): **1998-2024**

Groups of countries	Emerging EU-11			Emerging Non-EU-6		
Indep. Var. /PMG	PMG1	PMG2	PMG3	PMG4	PMG5	PMG6
Long-run coeff.						
Biomass	**0.128***** (0.042)	**15.894***** (5.426)	**1.826**** (0.752)	**0.090** (0.487)	**1.408**** (0.617)	**14.259***** (3.758)
Biomass^2	-	**-5.237***** (1.868)	**-0.516**** (0.268)	**-**	**-0.607**** (0.269)	**-4.906***** (1.428)
Fixed Capital Form.	0.271*** (0.024)	0.743*** (0.245)	0.496*** (0.031)	2.546*** (0.428)	0.264*** (0.043)	3.313*** (0.078)
Trade openess	0.118*** (0.029)	0.652*** (0.195)	0.142** (0.061)	0.436** (0.188)	-0.0001 (0.161)	-2.406*** (0.916)
Inflation	0.011*** (0.002)	-0.062** (0.032)	-0.004 (0.005)	0.008 (0.036)	0.009*** (0.003)	0.031 (0.072)
Stringency	-	-	-0.023*** (0.003)	-	-	-0.148* (0.070)
Error Correction Term	-0.359*** (0.082)	-0.051*** (0.015)	-0.233*** (0.041)	-0.079* (0.045)	-0.545*** (0.304)	-0.048*** (0.018)
Half-life (in years)	2.786	19.445	4.297	12.658	1.835	20.950
Hausman Test : MG versus PMG	4.47 (0.3463)	2.38 (0.6660)	9.03 (0.1079)	4.25 (0.3732)	4.07 (0.3960)	0.53 (0.9702)
Hausman Test : MG versus DFE	0.00 (1.000)	0.00 (1.000)	0.00 (1.000)	-0.00 (chi2<0)	0.00 (1.000)	0.08 (0.9999)

Note: i) ***, ** and * - significance at 1%, 5% and 10% levels, respectively; ii) "chi2<0" means that the model fitted on these data fails to meet the asymptotic assumptions of the Hausman test which is Test of H0: Difference in coefficients not systematic.

Table 9 (next): PMG estimations for EEC countries (linear and non-linear estimates): **1998-2024**

Groups of countries	Emerging EU-11 (EEU_11)			Emerging Non-EU-6 (NEU_6)		
Indep. Var. /PMG	PMG1	PMG2	PMG3	PMG4	PMG5	PMG6
Short-run coeff.						
Δ GDPpc $_{t-1}$	0.130***	0.051	0.027	-0.112	0.141	0.089
	(0.037)	(0.071)	(0.065)	(0.142)	(0.111)	(0.066)
Δ GDPpc $_{t-2}$	0.248***	0.189***	0.138***	0.079	0.298**	0.041
	(0.070)	(0.068)	(0.055)	(0.145)	(0.135)	(0.166)
Δ GDPpc $_{t-3}$	-	-	-	-0.114*	0.084	0.003
				(0.065)	(0.087)	(0.127)
Δ GDPpc $_{t-4}$	-	-	-	-0.223**	-0.010	0.281**
				(0.099)	(0.122)	(0.115)
Δ GDPpc $_{t-5}$	-	-	-	-0.191*	-0.101	-0.314***
				(0.109)	(0.112)	(0.114)
Δ Biomass	**-0.005**	**0.311**	**0.095**	**0.070***	**0.469**	**-0.390**
	(0.018)	(0.520)	(0.362)	(0.041)	(0.388)	(1.386)
Δ Biomass²	-	**-0.118**	**-0.026**	**-**	**-0.185**	**0.159**
		(0.210)	(0.146)		(0.166)	(0.610)
Δ Fixed Capital Form.	0.119**	0.221***	0.157***	0.012	0.004	0.047
	(0.051)	(0.028)	(0.032)	(0.046)	(0.062)	(0.061)
Δ Trade openess	0.179***	0.159***	0.157***	0.098	0.166*	0.161*
	(0.043)	(0.051)	(0.049)	(0.080)	(0.088)	(0.009)
Δ Inflation	0.003	0.005*	0.006**	-0.002	-0.011***	-0.004
	(0.002)	(0.003)	(0.002)	(0.004)	(0.003)	(0.004)
Δ Stringency	-	-	0.0001	-	-	-0.013***
			(0.002)			(0.005)
Constant	2.649***	-0.374***	1.285***	-0.063	3.637*	-0.028
	(0.570)	(0.120)	(0.009)	(0.039)	(2.112)	(0.025)
Trend	0.010***	-	0.006***	-	0.017*	-
	(0.003)		(0.001)		(0.011)	
No. Obs.(N x T)	264	264	264	126	126	126
No. Countries	11	11	11	6	6	6
ARDL(p,q) with AIC	(3,1,1,1,1,1)	(3,1,1,1,1,1)	(3,1,1,1,1,1)	(6.1,1,1,1,1)	(6,1,1,1,1,1)	(6,1,1,1,1,1,1)
Log-Likehood	701.369	699.153	744.771	343.205	379.942	380.832

Table 10: Granger Causality Results: **1998-2019**

Emerging EU-11/Dependent Variable	Short-run		Long-run ECT
	Δ GDP	**Δ Biomass**	
Δ GDP	-	-0.030*** (0.011)	-0.331***(0.071)
Δ Biomass	-0.009 (0.100)	-	-1.086*** (0.204)
Emerging non EU-6/Dependent Variable	Short-run		Long-run ECT
	Δ GDP	**Δ Biomass**	
Δ GDP	-	-0.196 (0.440)	-0.039***(0.019)
Δ Biomass	-0.452*** (0.168)	-	-0.067*** (0.155)

Note: i) ***, ** and * - significance at 1%, 5% and 10% levels, respectively

Table 11: Granger Causality Results: **1998-2024** (the models exclude the stringency index)

Emerging EU-11/Dependent Variable	Short-run		Long-run ECT
	Δ GDP	**Δ Biomass**	
Δ GDP	-	-0.005 (0.018)	-0.359***(0.082)
Δ Biomass	1.049*** (0.281)	-	-0.908*** (0.173)
Emerging non EU-6/Dependent Variable	Short-run		Long-run ECT
	Δ GDP	**Δ Biomass**	
Δ GDP	-	0.070*(0.041)	-0.079*(0.045)
Δ Biomass	0.304*** (0.037)	-	-0.019 (0.133)

Note: i) ***, ** and * - significance at 1%, 5% and 10% levels, respectively

Table 12: Granger Causality Results: **1998-2024** (the models include the stringency index)

Emerging EU-11/Dependent Variable	Short-run		Long-run ECT
	Δ GDP	**Δ Biomass**	
Δ GDP	-	-0.021 (0.017)	-0.278***(0.045)
Δ Biomass	1.234*** (0.250)	-	-0.834*** (0.132)
Emerging non EU-6/Dependent Variable	Short-run		Long-run ECT
	Δ GDP	**Δ Biomass**	
Δ GDP	-	0.102***(0.018)	-0.230*** (0.118)
Δ Biomass	0.886 (0.763)	-	-0.438** (0.202)

Note: i) ***, ** and * - significance at 1%, 5% and 10% levels, respectively.

Table 13: PSTR estimates for the emerging EU_11: **1998-2019**

PSTR Model 1	Threshold : 0.605/ Speed of transition : 5.0224			
GDPG – dependent variable *BIOMASG-1 - transition variable*	*EU_11 countries with c= -0.5025*			
Explanatory variables - X_{ikt}	$\beta_k^{(0)}$	t-stat	$\beta_k^{(1)}$	t-stat
$BIOMASG_{i,t-1}$	0.6719***	2.9184	-0.7483***	-2.9312
$FBKG_{it,\_1}$	1.1095**	2.2168	-1.0473*	-1.9220
$INF_{i,t-1,}$	0.0207	0.5416	-0.0290	-0.7014
AIC , BIC Criterion	-6.600		-6.646	
RSS	0.267			
Linearity test (p-value)	LM : 9.886** (0.020)	LMF : 3.321** (0.023)	LRT : 10.115** (0.018)	
No remaining non-linearity	LM : 3.949 (0.267)	LMF : 3.321 (0.304)	LRT : 3.984 (0.263)	
PSTR Model 2	Threshold : 0.781 bp/ Speed of transition : 5189.0			
GDPG – dependent variable *BIOMASG-1 - transition variable*	*EU_11 countries with c= -0.2477*			
Explanatory variables - X_{ikt}	$\beta_k^{(0)}$	t-stat	$\beta_k^{(1)}$	t-stat
$BIOMASG_{i,t-1}$	0.0589	0.6285	-0.1101	-1.1509
$FBKG_{i,t-1}$	0.3783***	5.8073	-0.2586***	-3.4229
$INF_{i,t-1}$	-0.0060	-0.5763	-0.0012	-0.1136
$GDP\ initial_{it,}$	0.0207[a]	-1.5291	-0.0290**	2.0199
AIC , BIC Criterion	-6.581		-6.657	
RSS	0.272			
Linearity test (p-value)	LM : 10.020** (0.040)	LMF : 2.446** (0.048)	LRT : 10.256** (0.036)	
No remaining non-linearity	LM : 5.447 (0.244)	LMF : 1.250 (0.291)	LRT : 5.515 (0.238)	

Note: i) ***, ** and * - significance at 1%, 5% and 10% levels, respectively; [a]- significance at 11-12%, ii) Tests for linearity reject the hypothesis of a homogeneous relationship between economic growth and biomass, as p-values are statistically significant at the 5% level; iii) tests for remaining non-linearity show one optimal threshold at c = -0.5025, with a smooth transition speed of γ = 5.0224; iv) PSTR 2 has the same features in terms of tests of linearity and non-linearity and identifies c=-0.248.

Table 14: PSTR estimates for the emerging EU_11: **1998-2024**

PSTR Model 1	Threshold : 0.976/ Speed of transition : 16394			
GDPG – dependent variable BIOMASG-1 - transition var.	*EU_11 countries with c= -0.0242*			
Explanatory variables - X_{ikt}	$\beta_k^{(0)}$	t-stat	$\beta_k^{(1)}$	t-stat
$BIOMASG_{i,t-1}$	1.4702	0.9528	-1.1451	-0.4425
$FBKG_{it,\_1}$	0.2001***	3.7500	-0.1373*	-1.9094
$INF_{i,t-1,}$	-0.1298	-1.1702	-0.3011**	-2.4060
AIC , BIC Criterion	0.690		0.795	
RSS	500.124			
Linearity test (p-value)	LM : 5.091 (0.165)		LMF : 1.641 (0.180)	LRT : 5.139 (0.162)
No remaining non-linearity	LM : 5.716 (0.126)		LMF : 1.804 (0.147)	LRT : 5.176 (0.123)
PSTR Model 2	Threshold : 1.131 bp/ Speed of transition : 10.8659			
GDPG – dependent variable BIOMASG-1 - transition var.	*EU_11 countries with c= 0.1231*			
Explanatory variables - X_{ikt}	$\beta_k^{(0)}$	t-stat	$\beta_k^{(1)}$	t-stat
$BIOMASG_{i,t-1}$	0.3155	0.1260	-1.3931	-0.3006
$FBKG_{i,t-1}$	0.1663***	2.7935	-0.2754	-1.5814
$INF_{i,t-1}$	--0.4327***	-3.2128	-0.1791	-0.4858
$GDP\ initial_{it,}$	-2.2799***	-6.7365	0.0365	0.1679
$String_{i,t-1,}$	0.1914*	1.9074	0.3315	1.5355
AIC , BIC Criterion	0.603		0.761	
RSS	438.835			
Linearity test (p-value)	LM : 6.589 (0.253)		LMF : 1.272 (0.277)	LRT : 6.669 (0.246)
No remaining non-linearity	LM : 1.578 (0.904)		LMF : 0.287 (0.920)	LRT : 1.582 (0.903)
PSTR Model 3	Threshold : 1.152/ Speed of transition : 11.8049			
GDPG – dependent variable BIOMASG-1 - transition var.	*EU_11 countries with c= 0.1408*			
Explanatory variables - X_{ikt}	$\beta_k^{(0)}$	t-stat	$\beta_k^{(1)}$	t-stat
$FBKG_{it,\_1}$	0.1763***	3.0301	-0.3678*	-1.9713
$INF_{i,t-1}$	-0.3973***	-3.2876	-0.2066	-0.5897
$GDP\ initial_{i,t-1,}$	-1.6502***	-5.7665	0.0383	0.6864
$String_{i,t,}$	-0.1033	-0.7164	0.1116	0.2696
AIC , BIC Criterion	0.656		0.791	
RSS	451.768			
Linearity test (p-value)	LM : 8.665* (0.070)		LMF : 2.113* (0.080)	LRT : 8.811* (0.060)
No remaining non-linearity	LM : 3.346 (0.502)		LMF : 0.773 (0.543)	LRT : 3.367 (0.498)

Note: i) $^{***, **}$ and * - significance at 1%, 5% and 10% levels, respectively; ^{a}- significance at 11-12%, ii) Tests for linearity reject the hypothesis of a homogeneous relationship between economic growth and biomass, as p-values are statistically significant at the 5% level, only in the last PSTR3 model; iii) PSTR3 tests for remaining non-linearity show one optimal threshold at c = 0.1408, with a smooth transition speed of γ = 11.8049; iv) PSTR 1 and PSTR 2 has the same features in terms of tests of linearity and non-linearity.